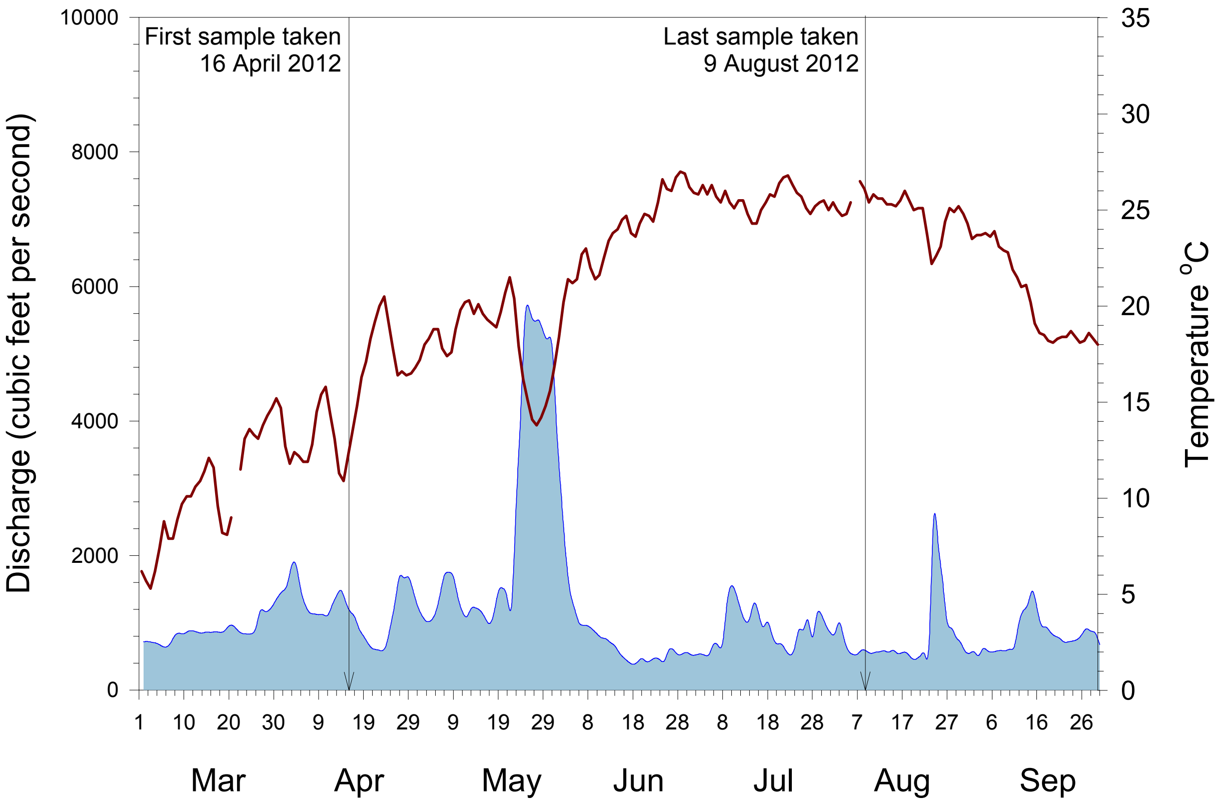
Colorado pikeminnow and razorback sucker larval fish survey in the San Juan River during 2012

FINAL REPORT



Michael A. Farrington, W. Howard Brandenburg, and Steven P. Platania
American Southwest Ichthyological Researchers L.L.C.
800 Encino Place NE
Albuquerque, New Mexico 87102-2606

SAN JUAN RIVER BASIN RECOVERY IMPLEMENTATION PROGRAM
Cooperative agreement # 07-FG-40-2642

Colorado pikeminnow and razorback sucker larval fish survey in the San Juan River during 2012

FINAL REPORT

prepared by:

Michael A. Farrington, W. Howard Brandenburg, and Steven P. Platania
American Southwest Ichthyological Researchers L.L.C.
800 Encino Place NE
Albuquerque, New Mexico 87102-2606

submitted to:

San Juan River Basin Biology Committee
under the authority of the
San Juan River Basin Recovery Implementation Program

30 June 2013

Table of Contents

page
List of Tables ii

List of Figures iii

Executive Summary 1

Introduction 2
Objectives 5
Study Area 6

Methods 6

Results 11
2012 Summary 11
Isolated Pools 15
2012 Trip Summary 15
Endangered Species 16
razorback sucker 16
Colorado pikeminnow 22
Native Species 22
speckled dace 22
flannelmouth sucker 27
bluehead sucker 27
Non-Native Species 27
red shiner 27
common carp 27
fathead minnow 27
channel catfish 32
Native and Non-Native Catch 32
Monitoring Sites 32
RERI Sites 36

Discussion 36

Acknowledgments 40

Literature Cited 41

Appendix A 45

List of Tables

page

Table 1. Summary of larval Colorado pikeminnow collected in the San Juan River (1993-2011) and back-calculated dates of spawning. 4

Table 2. Summary of larval and YOY razorback sucker collected in the San Juan River (1998-2011). 5

Table 3. Scientific and common names and species codes of fish collected from the San Juan River. Asterisk (*) indicates species collected in previous years, but absent from 2012 samples. 10

Table 4. Species composition and habitat type of the six RERI sites sampled in 2012. 37

Table A-1. Locality and description of the monitoring sites designated for habitat persistence. 47

Table A-2. Summary of age-0 fishes collected during the 2012 San Juan River larval Colorado pikeminnow and razorback sucker survey. Effort =8,269.8 m^2 48

Table A-3. Summary of age-1+ fishes collected during the 2012 San Juan River larval Colorado pikeminnow and razorback sucker survey. Effort =8,269.8 m^2 49

Table A-4. Summary of the age-0 razorback sucker collected in the San Juan River during the May larval fish survey. 50

Table A-5. Summary of the age-0 razorback sucker collected in the San Juan River during the June larval fish survey. 51

Table A-6. Habitat type of each monitoring site during 2011 and 2012. Discharge data taken from USGS gage #09379500 (Mexican Hat, UT); values are means for the week the site was sampled. 52

List of Figures

page

Figure 1. Map of the San Juan River. Study area is delineated by red bars (Shiprock, NM river mile 147.9 and Clay Hills Crossing, UT river mile 2.9). 7

Figure 2. Discharge (cfs) and temperature (^{o}C) in the San Juan River during the 2012 sampling period. Grey vertical bars denote individual collecting trips. 12

Figure 3. Map of the 2012 sampling localities. 13

Figure 4. Occurrence of larval fishes in the San Juan River during 2012 plotted against discharge and water temperature. Bars represent the period between date of first and last collection of larvae for each species. Blue bars denote native species, yellow bars denote non-native species. 14

Figure 5. Map of the 2012 age-0 razorback sucker capture localities. 17

Figure 6. ln(CPUE per 100 m^2 +1) [+1 *SE*] for razorback sucker by habitat type sampled from 1999 to 2012. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicated that no fish were collected. 18

Figure 7. Percent frequency of occurrence for razorback sucker from 1999 to 2012. 18

Figure 8. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 razorback sucker by trip (top graph), reach, and riverwide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter were significantly different and open circles indicate that no fish were collected. 19

Figure 9. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 razorback sucker by year (April - June 1999-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 19

Figure 10. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 razorback sucker by month (April-June 1999-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 20

Figure 11. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 razorback sucker by reach (April-June 1999-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 20

Figure 12. Catch per unit effort /100 m^2 of discrete ontogenetic stages (protolarvae, mesolarvae, metalarvae, and juvenile) of razorback sucker by sample locality during the 2012 survey. Blue bars represent May collections and green bars June collections. 21

List of Figures Cont.

page

Figure 13. Back-calculated hatching dates for razorback sucker plotted against discharge and water temperature. Grey box delineates hatching period with mean (min max) discharge and water temperature reported. 23

Figure 14. ln(CPUE per 100m^2 +1) for age-0 Colorado pikeminnow by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. Open circles indicate that no fish were collected. 24

Figure 15. ln(CPUE per 100m^2 +1) for age-1+ Colorado pikeminnow by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 24

Figure 16. Catch per unit effort /100 m^2 of age-1+ Colorado pikeminnow (N= 114) by sampling locality during the 2012 larval fish survey. 25

Figure 17. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 speckled dace by trip (top graph), reach, and riverwide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected. 26

Figure 18. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 speckled dace by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 26

Figure 19. ln(CPUE per 100 m^2 +1) [+1 *SE]* for age-0 flannelmouth sucker by trip (top graph), reach, and riverwide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 28

Figure 20. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 flannelmouth sucker by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 28

Figure 21. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 bluehead sucker by trip (top graph), reach, and riverwide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected. 29

Figure 22. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 bluehead sucker by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 29

List of Figures Cont.

page

Figure 23. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 red shiner by trip (top graph), reach, and riverwide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected. 30

Figure 24. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 red shiner by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 30

Figure 25. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 common carp by trip (top graph), reach, and riverwide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected. 31

Figure 26. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 common carp by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 31

Figure 27. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 fathead minnow by trip (top graph), reach, and riverwide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected. 33

Figure 28. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 fathead minnow by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 33

Figure 29. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 channel catfish by trip (top graph), reach, and riverwide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected. 34

Figure 30. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 channel catfish by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different. 34

Figure 31. ln(CPUE per 100 m^2 +1) [+1 *SE*] of non-native taxa and native taxa from 2003-2012. Sample size reported on the x-axis labels. 35

Figure A-1. Example of field data recorded at each sampling locality. 46

Executive Summary

1. From 16 April to 9 August 2012 five monthly larval survey trips were conducted between river miles 147.9 (Shiprock, NM) and 2.9 (Clay Hills Crossing, UT) on the San Juan River.

2. During the study period mean daily discharge and water temperature in the San Juan River was 1,287 cfs (383 – 5,650 cfs) and 21.9 ^{o}C (12.2 – 27.0 ^{o}C).

3. A total of 296 collections were made encompassing 8,269.8 m^2 of low velocity habitat.

4. The 2012 larval fish collections produced 29,384 fishes representing six families and 16 species.

5. Age-0 fishes accounted for 94.9% of the total catch (n = 27,888) and had a river wide mean of 375.6 (*SE* = 52.7) fish per 100 m^2.

6. Bluehead sucker was the numerically dominant (n = 7,944) species during the 2012 larval fish survey.

7. Between 14 May and 14 June 2012, 1,778 wild age-0 razorback sucker were collected in seven different habitat types.

8. A single habitat type (isolated pool) contained 67.1% (n = 1,193) of all age-0 razorback sucker collected in 2012.

9. The back-calculated hatching dates for razorback sucker ranged from 5 April to 5 June 2012. Mean daily discharge and water temperature during that period was 1,842 cfs and 17.1 ^{o}C.

10. Age-0 razorback sucker consisted primarily of mesolarvae and metalarvae (n = 1,542 and n = 183, respectively).

11. No age-0 Colorado pikeminnow were collected in 2012.

12. A total of 114 age-1+ (34 – 116 mm SL, 42 – 140 mm TL) Colorado pikeminnow were collected during the study period in 2012. It is presumed these fish were the result of augmentation efforts.

13. For the second consecutive year, age-0 roundtail chub were collected in the San Juan River.

14. Each of the six River Ecosystem Restoration Initiative (RERI) sites that were constructed in late 2011 were sampled multiple times during the 2012 survey.

15. The RERI sites all contained suitable nursery habitat and produced age-0 fish, including two razorback sucker mesolarvae.

Introduction

Colorado pikeminnow, *Ptychocheilus lucius*, and razorback sucker, *Xyrauchen texanus,* are two endangered species of cypriniform fishes native to the San Juan River, a large tributary of the Colorado River. The decline of these and other native fishes in the San Juan River has been attributed to flow modifications, instream barriers, changes to the thermal regime and channel simplification. In addition, the introduction of non-native fishes may have altered predation dynamics and competition for habitat and resources (Clarkson and Childs, 2000).

Colorado pikeminnow (family Cyprinidae) was listed as an endangered species by the U.S. Department of the Interior in 1974. It is endemic to the Colorado River Basin where it was once abundant and widespread (Tyus, 1991). Currently this species occupies only about 20% of its historical range (Behnke and Benson, 1983; Tyus, 1990), with the majority of the remaining Upper Basin individuals occurring in the Green River (Holden and Wick, 1982; Bestgen et al., 1998). No Colorado pikeminnow have been reported in the Lower Basin since the 1960's (Minckley and Deacon, 1968; Minckley, 1973; Moyle, 2002).

Studies in the Upper Colorado River Basin (Yampa and Green Rivers) demonstrated that Colorado pikeminnow spawn on the descending limb of the summer hydrograph at water temperatures between 20^{o}C and 25^{o}C (Haynes et al., 1984; Nesler et al., 1988). Larval Colorado pikeminnow drift down river as a dispersal mechanism and appear to begin this passive movement approximately five days after hatching. The five-day time frame corresponds with the swim-up period of this fish as reported by Hamman (1981, 1986). Drift of the newly hatched larval fish counteracts upstream migrations of the adults and disperses offspring to favorable nursery habitats downstream.

Razorback sucker (family Catostomidae) was listed as an endangered species in 1991. There are few historical San Juan River records of razorback sucker despite the fact that this is one of three endemic Colorado River Basin catostomids. There are anecdotal reports from the late 1800's of razorback sucker occurring in the Animas River as far upstream as Durango, Colorado (Jordan, 1891). There are no specimens to substantiate this claim. The first verified record of razorback sucker in the San Juan River was in 1976 when two adult specimens were collected in an irrigation pond near Bluff, Utah (VTN Consolidated, Inc., and Museum of Northern Arizona, 1978).

Spawning of razorback sucker has been associated with the ascending limb of the spring hydrograph, peak spring discharge, and warming river temperatures. Adults congregate in riffles with cobble, gravel, and sand substrates. Spawning has been documented from mid-April to early June in the Green River at mean water temperatures of 14^{o}C (Tyus and Karp, 1990). Razorback sucker larvae have been collected from Lake Mohave at 9.5 – 15.0^{o}C, indicating successful incubation of eggs at these temperatures (Bozek et al., 1990). Spawning of razorback sucker coincides with spawning of other native catostomids. Hybridization between flannelmouth sucker and razorback sucker has been documented where these two species co-occur (Tyus and Karp, 1990; Douglas and Marsh, 1998).

Mortality rates are substantial in the early ontogeny of fishes (Harvey,1991; Jennings and Philipp, 1994). Biotic and abiotic factors often operate simultaneously and affect the survival rates of larval fishes. Starvation, the presence and duration of important environmental conditions, and biotic interactions such as competition and predation all affect the survival of larvae (Bestgen, 1996). Early-life mortality can be especially significant in populations of slow growing fishes (Kaeding and Osmundson, 1988) such as Colorado pikeminnow and razorback sucker. Abiotic factors, such as water temperature and discharge, act as cues for spawning of adult fishes but also affect growth rates, available food supplies, and mortality rates, for their offspring (Miller et al., 1988).

Food production, competition for food resources, and predation, especially in limited nursery habitats, result in high mortality rates of larval fishes (Houde, 1987). These factors are compounded in modified systems with large numbers of non-native fishes. For example, non-native red shiner, *Cyprinella lutrensis*, preys on cypriniform larvae (Brandenburg and Gido, 1999; Bestgen and Beyers, 2006). Red shiner can compose up to 80% of the ichthyofaunal community in nursery habitats in the San Juan River (Propst et al., 2003; Brandenburg and Farrington, 2010) and may have significant impacts on native fish populations.

To mitigate these negative effects, attempts to mimic natural flow regimes in regulated systems are used to maintain cues for activities such as spawning and migration of native fishes, create and maintain nursery habitat for larval fishes, and suppress non-native fish populations (Poff et al., 1998). Natural flow regimes also favor the downstream displacement or drifting behavior of larval fishes and exploitation of the most advantageous feeding and rearing areas (Muth and Schmulbach, 1984; Pavlov, 1994). In many western river systems, higher spring and early summer flows increase sediment transport and turbidity and have been shown to reduce predation of larvae (Johnson and Hines, 1999). Sediment transport during high spring flows also scours substrates providing critical spawning habitat to native catostomids (Osmundson et al., 2002).

Investigations into the reproductive success of Colorado pikeminnow began on the San Juan River using larval drift net surveys from 1991 to 2001. During that period of passive sampling only six larval Colorado pikeminnow were collected.

Beginning in 2002, the sampling protocol was switched to active collection of larval fishes using larval seines and a raft to navigate the San Juan River. Using this active approach a total of 40 larval Colorado pikeminnow were collected between 2004 and 2011 (Table 1).

Larval surveys using the same active sampling methods as that for the larval Colorado pikeminnow survey began in 1998 on the San Juan River in an attempt to document reproduction of stocked razorback sucker. The 1998 survey produced the first documentation of reproduction by stocked razorback sucker. Larval razorback sucker have been documented every year since (Table 2).

Table 1. Summary of larval Colorado pikeminnow collected in the San Juan River (1993-2011) and back-calculated dates of spawning.

Field Number	MSB Catalog Number	Number of specimens	Total Length mm	Date Collected	Date Spawned	River Mile	Sample Method
MH72693-2	18098	1	9.2	26 Jul 93	08 Jul 93	53.0	drift netting
MH72793-2	18099	1	9.2	27 Jul 93	09 Jul 93	53.0	drift netting
JPS95-205	26187	1	9.2	02 Aug 95	15 Jul 95	53.0	drift netting
JPS95-207	26191	1	9.0	03 Aug 95	17 Jul 95	53.0	drift netting
WHB96-037	29717	1	8.6	02 Aug 96	18 Jul 96	128.0	drift netting
FC01-054	50194	1	8.5	01 Aug 01	17 Jul 01	128.0	drift netting
MAF04-046	53090	1	14.2	22 Jul 04	24 Jun 04	46.3	larval seine
MAF04-059	53130	1	18.1	26 Jul 04	25 Jun 04	17.0	larval seine
MAF07-139	70144	1	14.9	25 Jul 07	27 Jun 07	107.7	larval seine
MAF07-157	70145	1	17.5	27 Jul 07	27 Jun 07	74.9	larval seine
WHB07-078	64032	1	15.6	25 Jul 07	27 Jun 07	33.7	larval seine
MAF09-072	74264	1	25.2	29 Jul 09	10 Jun 09	24.7	larval seine
MAF10-140	82014	1	12.6	23 Jul 10	23 Jun 10	58.9	larval seine
WHB10-096	82040	3	19.7-21.4	20 Jul 10	15-18 Jun 10	41.5	larval seine
WHB10-106	82071	1	16.2	22 Jul 10	23 Jun 10	13.0	larval seine
MAF11-114	86309	3	10.6-11.8	20 Jul 11	23-25 Jun 11	87.4	larval seine
WHB11-122	86561	21	10.0-12.9	21 Jul 11	25-29 Jun 11	10.8	larval seine
WHB11-124	86573	3	11.8-15.2	21 Jul 11	29 Jun-1 Jul 11	10.0	larval seine
WHB11-153	86656	1	21.3	10 Aug 11	5 Jul 11	92.6	larval seine
MAF11-149	86411	1	17.3	11 Aug 11	12 Jul 11	7.0	larval seine
TOTAL		**46**					

Table 2. Summary of larval and YOY razorback sucker (Xyrtex) collected in the San Juan River (1998-2011).

Year	Study Area (RM)	Project Dates	Total Effort m^2	Xyrtex	Sample Method
1998	127.5 - 53.0	17 Apr - 6 Jun	-	2	larval seine/ light trap
1999	127.5 - 2.9	5 Apr - 10 Jun	2,713.5	7	larval seine/ light trap
2000	127.5 - 2.9	4 Apr - 23 Jun	2,924.6	129	larval seine/ light trap
2001	141.5 - 2.9	10 Apr - 14 Jun	5,733.1	50	larval seine/ light trap
2002	141.5 - 2.9	15 Apr - 12 Sep	9,647.5	815	larval seine/ light trap
2003	141.5 - 2.9	15 Apr - 19 Sep	13,564.6	472	larval seine
2004	141.5 - 2.9	19 Apr - 14 Sep	11,820.3	41	larval seine
2005	141.5 - 2.9	19 Apr - 14 Sep	10,368.6	19	larval seine
2006	141.5 - 2.9	17 Apr - 15 Sep	12,582.6	202	larval seine
2007	141.5 - 2.9	16 Apr - 19 Sep	13,436.0	200	larval seine
2008	141.5 - 2.9	14 Apr - 13 Sep	14,292.3	126	larval seine
2009	141.5 - 2.9	13 Apr - 26 Sep	15,860.3	272	larval seine
2010	141.5 - 2.9	19 Apr - 3 Sep	16,761.0	1,251	larval seine
2011	141.5 - 2.9	18 Apr - 11 Aug	9,387.9	1,065	larval seine
TOTAL				**4,651**	

Objectives

This work was conducted as required by the San Juan River Basin Implementation Program (2011) Long Range Plan. The goals and objectives of this specific monitoring project are identified in the aforementioned document and listed below:

- 4.1.2.1 Determine if razorback sucker and Colorado Pikeminnow reproduction occurred in the San Juan River and estimate the extent of annual reproduction.
- 4.1.2.5 Collect catch rate (CPUE) statistics to estimate relative abundance of endangered fish populations.
- 4.2.2.1 Quantify attributes of habitats important to each life-stage of endangered fish.
- 4.2.3.2 Document and track trends in the use of specific mesohabitat types by larval Colorado pikeminnow and razorback sucker
- 4.1.1.1 Document and provide a comparative analysis of the reproductive effort of the entire ichthyofaunal community.
- 4.1.1.2 Analyze and evaluate monitoring data and produce Annual Fish Monitoring Reports to ensure that the best sampling design and strategies are employed.

Study Area

The San Juan River is a major tributary of the Colorado River and drains 38,300 mi^2 in Colorado, New Mexico, Utah, and Arizona (Figure 1). The major perennial tributaries to the San Juan River are (from upstream to downstream) Navajo, Piedra, Los Pinos, Animas, La Plata, and Mancos rivers, and McElmo Creek. In addition there are numerous ephemeral arroyos and washes that contribute relatively little flow annually but input large sediment loads during rain events.

The San Juan River is currently a 224 mile lotic system bounded by two reservoirs (Navajo Reservoir near its head and Lake Powell at its mouth). From Navajo Dam to Lake Powell, the mean gradient of the San Juan River is 10.1 ft/mi, but can be as high as 21.2 ft/mi. Except in canyon-bound reaches, the river is bordered by non-native salt cedar, *Tamarix chinensis*, Russian olive, *Elaeagnus angustifolia*, native cottonwood, *Populus fremontii*, and willow, *Salix* sp. Non-native woody plants dominate nearly all sites and result in heavily stabilized banks. Cottonwood and willow compose a small portion of the riparian vegetation.

The characteristic annual hydrographic pattern in the San Juan River is typical of rivers in the American Southwest, with large flows during spring snowmelt followed by low summer, autumn, and winter base flows. Summer and early autumn base flows are frequently punctuated by convective storm-induced flow spikes. Prior to operation of Navajo Dam, about 73% of the total annual San Juan River drainage discharge (based on USGS Gage # 09379500; Bluff, Utah) occurred during spring runoff (1 March through 31 July). Mean daily peak discharge during spring runoff was 10,400 cfs (range = 3,810 to 33,800 cfs). Although flows resulting from summer and autumn storms contributed a comparatively small volume to the total annual discharge, the magnitude of storm-induced flows exceeded the peak snowmelt discharge in about 30% of the years, occasionally exceeding 40,000 cfs (mean daily discharge). Both the magnitude and frequency of these storm induced flow spikes are greater than those recorded in the Green or Colorado Rivers.

Operation of Navajo Dam altered the annual discharge pattern of the San Juan River. The natural flow of the Animas River ameliorated some aspects of regulated discharge by augmenting spring discharge. Regulation resulted in reduced magnitude and increased duration of spring runoff in wet years and substantially reduced magnitude and duration of spring flow during dry years. Overall, flow regulation by operation of Navajo Dam has resulted in post-dam peak spring discharge averaging about 54% of pre-dam values. Conversely, post-dam base flow increased markedly over pre-dam base flows. Since 1992 efforts have been made to operate Navajo Dam to mimic a “natural” annual flow regime.

Methods

Access to the river and collection localities was gained through the use of 16' inflatable rafts that transported both personnel and collecting gear. There was not a predetermined number of collections per river mile or geomorphic reach for this study. Instead, collections were made in as many suitable larval fish habitats as possible within the river reach being sampled. Previous San Juan River investigations clearly demonstrated that larval fish most frequently occur and are most abundant in low velocity habitats such as pools and backwaters (Lashmett, 1993). Sampling of the entire study area was accomplished during a one week period in which the study area is divided into an “upper” section (Shiprock, NM to Sand Island, UT) and a “lower” section (Sand Island, UT to Clay Hills, UT). Sampling trips for both portions of the study area were initiated on the same day of each month whenever possible.

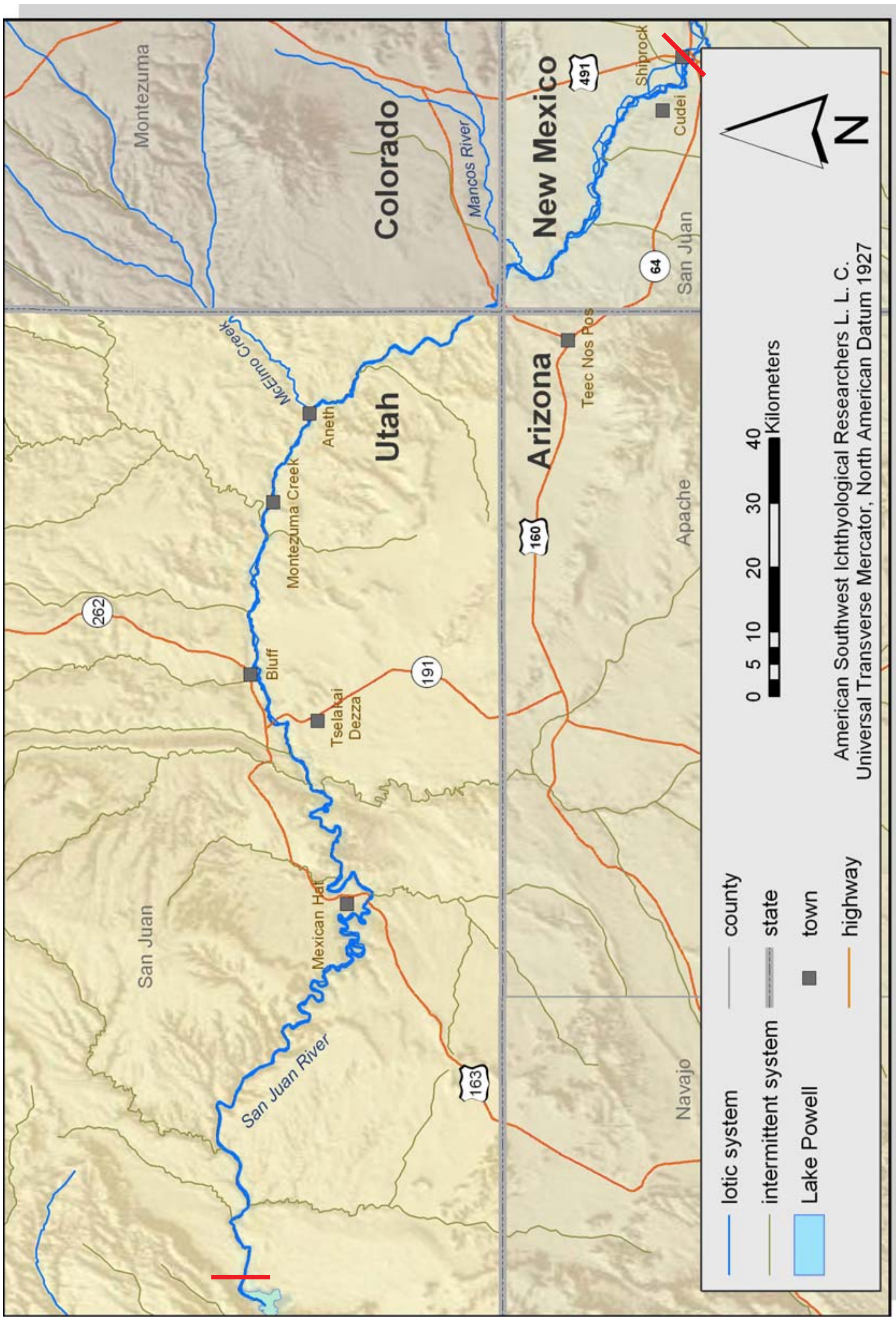


Figure 1. Map of the San Juan River. Study area is delineated by red bars (Shiprock, NM river mile 147.9 and Clay Hills Crossing, UT river mile 2.9).

Collecting efforts for larval fishes were concentrated in low velocity habitats using fine mesh larval fish seines (1 m x 1 m x 0.8 mm). Several seine hauls (between two and seven) were made through an individual mesohabitat depending on the size of that habitat. Fishes collected within an individual mesohabitat were preserved together as a single sample. For each site sampled, the length (in meters) of each seine haul was determined in addition to the number of seine hauls per site. Mesohabitat type, length, maximum and minimum depth, substrate, and turbidity (using a Secchi disk) were recorded in the field data sheet for the particular collecting site (Figure A-1). Water quality measurements (dissolved oxygen, conductivity, specific conductance, pH, salinity, and temperature) were also obtained using a multiparameter water quality meter. Habitat designations used in this report were developed for the San Juan River Basin Recovery Implementation Program's (SJRBRIP) monitoring projects (Bliesner et al., 2008). A minimum of one digital photograph was recorded at each collection site.

River mile was determined to the nearest tenth of a mile using the 2009 standardized aerial maps produced for the SJRBRIP and used to designate the location of collecting sites. In addition, geographic coordinates were determined at each site with a Garmin Geographic Positioning System (GPS) unit and were recorded in Universal Transverse Mercator (UTM) Zone 12 (NAD27). In instances where coordinates could not be obtained due to poor GPS satellite signal, coordinates were determined in the laboratory using a Geographic Information System based on the recorded river mile.

Beginning in 2011, ASIR researchers defined 20 monitoring sites throughout the study area in an attempt to assess persistence of backwaters habitats. All but three sites were geomorphically similar and were characterized as lateral washes or canyons which form backwaters during increased river discharge. In 2012 the three monitoring sites not located in lateral washes or canyons were excluded from analysis. In addition, two sites designated in Reach 5 were also excluded because one was fed by irrigation return water and the other was inaccessible at most discharge levels (Table A-1). Because these sites do not have perennial flow, the only habitat types encountered were either backwaters, or, after river levels have subsided, isolated pools. The 15 remaining monitoring sites were visited in each monthly survey. If suitable nursery habitats had formed in them at the time of visitation they were sampled. If they were dry or isolated, photographs were taken and field notes written detailing condition of the habitat. Conditions of monitoring sites were then related back to discharge at time of visitation.

Each of the six River Ecosystem Restoration Initiative (RERI) sites located between river miles 132.2 and 127.2 were also the subject of repeated monthly monitoring. Unlike the monitoring sites, these areas were only sampled if the existing habitat could be effectively sampled with larval fish seines. The goal of these collections was to detect the presence of fishes, regardless of age class. If a site could not be effectively sampled (either because of depth, or high water velocity), photos were taken and no collection made.

All retained specimens were placed in plastic bags (Whirl-Paks) containing a solution of 95% ethyl alcohol and a tag inscribed with unique a alpha-numeric code that was also recorded on the field data sheet. Samples were returned to the laboratory where they were sorted and identified to species. Specimens were identified by personnel with expertise in San Juan River Basin larval fish identification. Stereo-microscopes with transmitted light bases and polarized light filters were used to aid in identification of larval individuals. Age-0 specimens were separated from age-1+ specimens using published literature to define growth and development rates for individual species (Auer, 1982; Snyder, 1981; Snyder and Muth, 2004). Both age classes were enumerated, measured (minimum and maximum size [mm standard length] for each species at each site), and cataloged in the Division of Fishes of the Museum of

Southwestern Biology (MSB) at the University of New Mexico (UNM).

Results reported in this document pertain primarily to age-0 fishes. Raw numbers of age-1+ and age-0 fishes are presented in Appendix A (Tables A-2 and A-3). Scientific and common names of fishes used in this report follow Nelson et al. (2004) and six letter codes for species are those adopted by the San Juan River Basin Biology Committee (Table 3). Total length (TL) and standard length (SL) were measured on all Colorado pikeminnow and razorback sucker to be consistent with information gathered by the San Juan River Basin and Upper Colorado River Basin programs (Tables A-4 and A-5). Within this report, lengths of these species are given as TL.

The term young-of-year (YOY) can include both larval and juvenile fishes. It refers to any fish, regardless of developmental stage, between hatching or parturition and the date (1 January) that they reach age 1 (i.e., YOY = age-0 fish). Larval fish is a specific developmental (morphogenetic) period between the time of hatching and when larval fish transform to juvenile stage. The larval fish terminology used in this report is defined by Snyder (1981). There are three distinct sequential larval developmental stages: protolarva, mesolarva, and metalarva. Fishes in any of these developmental stages are referred to as larvae or larval fishes. Juvenile fishes are those that have progressed beyond the metalarva stage and no longer retain traits characteristic of larval fishes. Juveniles were classified as individuals that 1) had completely absorbed their fin folds, 2) had developed the full adult complement of rays and spines, and 3) had developed segmentation in at least a few of the rays.

Only larval specimens (protolarva, mesolarva, and metalarva) were used to generate the larval occurrence graph. The period of larval occurrence was determined by recording the first collection of larval fish within a given year for each species as the initial occurrence. The cessation of larval occurrence was developed using the mean standard length of transformation from metalarva to juvenile as a cut off (Snyder, 1981; Snyder and Muth, 2004). Larval occurrence was then plotted against discharge recorded at Mexican Hat, UT (USGS gage #9379500) and water temperature recorded at Mexican Hat, UT to describe an approximation for the timing and duration of larval occurrence within the San Juan River.

Differences in mean CPUE were determined by species among years, trips, and reaches using a one-way Analysis of Variance (ANOVA). Samples collected in isolated pools were not included in yearly or between year trend analysis. A variety of transformations (e.g., logarithmic, reciprocal, square root) were applied on the mean CPUE data for between year comparisons. A natural log-transformation yielded the best variance-stabilizing qualities and produced a relatively normal distribution. Pair-wise comparisons between years (2003 – 2012), trips and reaches were made for each species and significance (i.e., $p < 0.05$) was determined using the Tukey-Kramer HSD test. The exception is annual trend data in larval razorback sucker where catch rates were analyzed from 1999-2012 using only the months April – June. This was done in an effort to include data from the larval surveys conducted between 1999 – 2001 when the study period ended in June. Finally, a nonparametric Analysis of Variance (Kruskal–Wallis test) was run for the various data sets to compare results to the parametric analysis.

Although both ANOVA and Kruskal-Wallis were used to analyze data, data transformations enabled use of parametric analysis in all cases. The assumption of homogeneity of variances was assessed using the more conservative variance ratio criterion of <3:1 (Box, 1954), as opposed to <4:1 (Moore, 1995), among years. All species data sets met this more rigorous criterion and in most cases the variance ratio was <2:1 among years. Additionally, the significance values between parametric and nonparametric techniques were nearly identical and so only the parametric analysis are presented.

Hatching dates were calculated for larval Colorado pikeminnow using the formula: $-76.7105+17.4949(L)-1.0555(L)^2+0.0221(L)^3$ for larvae under 22 mm TL, where L = length (mm

Table 3. Scientific and common names and species codes of fish collected from the San Juan River. Asterisk (*) indicates species collected in previous years, but absent from 2012 samples.

Scientific Name	Common Name	Code
Order Cypriniformes		
Family Cyprinidae	carps and minnows	
Cyprinella lutrensis	red shiner	(CYPLUT)
Cyprinus carpio	common carp	(CYPCAR)
Gila robusta	roundtail chub	(GILROB)
Pimephales promelas	fathead minnow	(PIMPRO)
Ptychocheilus lucius	Colorado pikeminnow	(PTYLUC)
Rhinichthys osculus	speckled dace	(RHIOSC)
Family Catostomidae	suckers	
Catostomus (Pantosteus) discobolus	bluehead sucker	(CATDIS)
Catostomus latipinnis	flannelmouth sucker	(CATLAT)
Xyrauchen texanus	razorback sucker	(XYRTEX)
Order Siluriformes		
Family Ictaluridae	catfishes	
Ameiurus melas	black bullhead	(AMEMEL)
Ameiurus natalis	yellow bullhead	(AMENAT)
Ictalurus punctatus	channel catfish	(ICTPUN)
Order Salmoniformes		
Family Salmonidae	trouts	
*Oncorhynchus nerka**	kokanee salmon	(ONCNER)
Order Cyprinodontiformes		
Family Fundulidae	topminnows	
Fundulus zebrinus	plains killifish	(FUNZEB)
Family Poeciliidae	livebearers	
Gambusia affinis	western mosquitofish	(GAMAFF)
Order Perciformes		
Family Centrarchidae	sunfishes	
Lepomis cyanellus	green sunfish	(LEPCYA)
*Lepomis macrochirus**	bluegill	(LEPMAC)
Micropterus salmoides	largemouth bass	(MICSAL)

TL). For specimens 22 - 47mm TL the formula *A= -26.6421+2.7798L* is used. Spawning dates were then calculated by adding five days to the post-hatch ages to account for incubation time at 20 – 22°C (Nesler et al., 1988). Hatch dates of razorback sucker larvae were calculated by subtracting the average length of larvae at hatching (8.0 mm TL) from the total length at capture divided by 0.3 mm (Bestgen et al., 2002), which was the average daily growth rate of wild larvae observed by Muth et al. (1998) in the Green River UT. The back-calculated hatching formula was only applied to proto- and mesolarvae as growth rates become much more variable at later developmental stages (Bestgen, 2008).

Habitat occupancy graphs were generated using natural log transformed mean CPUE in order to measure density of age-0 species within sampled habitats. The larval surveys adopted the standardized habitat designations beginning in 2005. Data collected prior to 2005 were sorted by primary habitat type sampled and in some cases, primary and secondary habitat types were combined (i.e. pool + edge pool = pool) to reflect the current habitat designations (Bliesner et al., 2009) being used by the SJRBRIP.

This study was initiated prior to spring runoff and completed in the middle of the summer season (mid-August). Daily mean discharge during the study period was acquired from U.S. Geological Survey Gages near Four Corners, CO (#09371010) and Mexican Hat, UT (#09379500). Mexican Hat discharge and temperature were used for all data analysis in this report except for back-calculated spawning dates of Colorado pikeminnow in which Four Corners discharge and temperature were used. Temperature data (mean, max, min) were taken at the state highway 160 bridge crossing in Colorado (river mile 119.2) and Mexican Hat, UT (river mile 52.0).

Results

2012 Summary

The 2012 San Juan River larval fish survey encompassed a five-month period from 16 April to 9 August 2012. Monthly trips were conducted from river mile 147.9 (Shiprock, New Mexico) to river mile 2.9 (Clay Hills Crossing, Utah). During the study period, mean daily discharge and water temperature were 1,287 cfs (383 – 5,650 cfs) and 21.9 °C (12.2 – 27.0 °C). Spring releases out of Navajo Dam began on 21 May 2012 and discharge in the San Juan River peaked five days later at 5,650 cfs (Figure 2). Prior to the release of water from Navajo Dam, fluctuations in discharge in the San Juan River were a result of spring runoff in the Animas River, which began in mid-March. Spring releases out of Navajo Dam ceased six days after the 21 May peak, resulting in a steep slope to both the ascending and descending limbs of the spring hydrograph and mean river temperatures dropping by over seven degrees (Figure 2). Discharge in the San Juan River exceeded 5,000 cfs for a period of seven consecutive days as a result of water released from Navajo Reservoir.

During the 2012 larval fish survey, 296 collections were made in zero and low velocity habitats encompassing an area of 8,269.8 m^2 (Figure 3). Collections resulted in the capture of 29,384 age-0 and age-1+ fishes representing six families and 16 species (Tables A-2 and A-3). Age-0, or YOY fish, accounted for 94.9% of the total catch (n = 27,888). Age-0 fish were collected in each of the five monthly surveys (April – August) with a mean of 375.6 fish per 100 m^2 (SE = 52.7). Of the native species occurring in the San Juan River, bluehead sucker, *Catostomus discobolus*, had the highest mean CPUE of 99.5 fish per 100 m^2 (SE = 24.1). Native species made up 12.8% (n = 191) of the age-1+ catch and 67.9% (n = 18,929) of the age-0 catch by number during the 2012 larval survey.

Flannelmouth sucker, *Catostomus latipinnis*, was the first and only age-0 fish collected during the April survey. Collection of all three native catostomid species occurred during the May

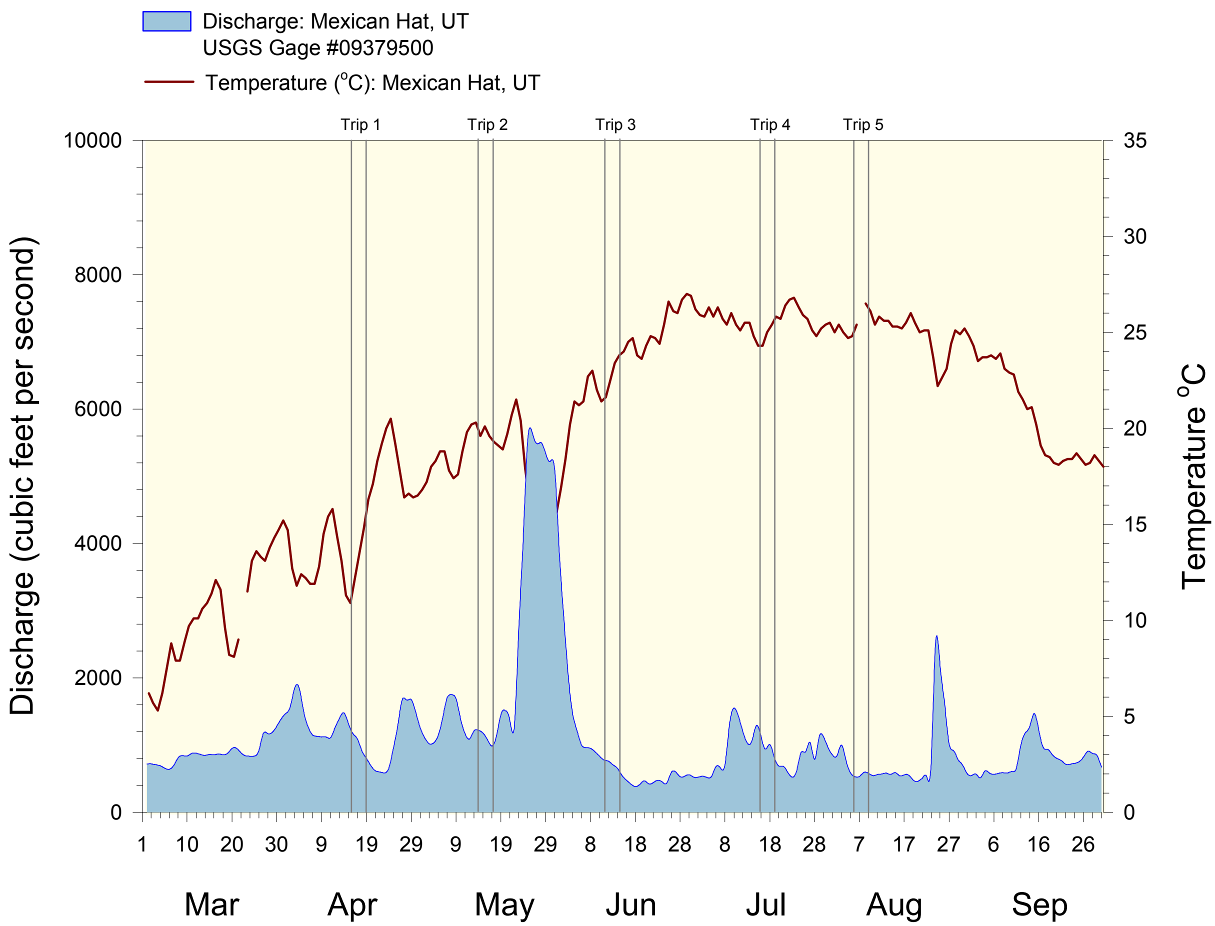


Figure 2. Discharge (cfs) and temperature (°C) in the San Juan River during the 2012 sampling period. Grey vertical bars denote individual collecting trips.

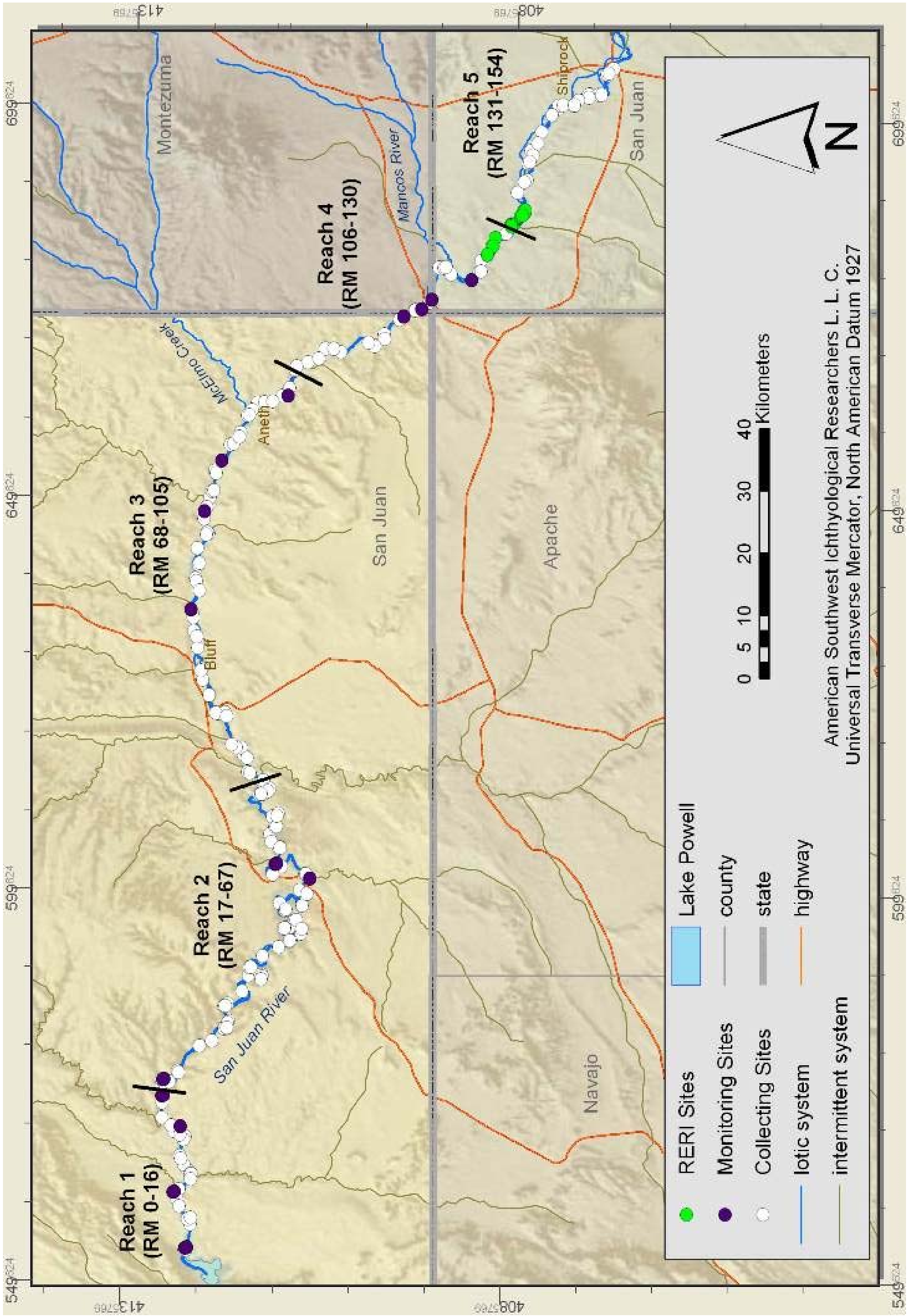


Figure 3. Map of the 2012 sampling localities.

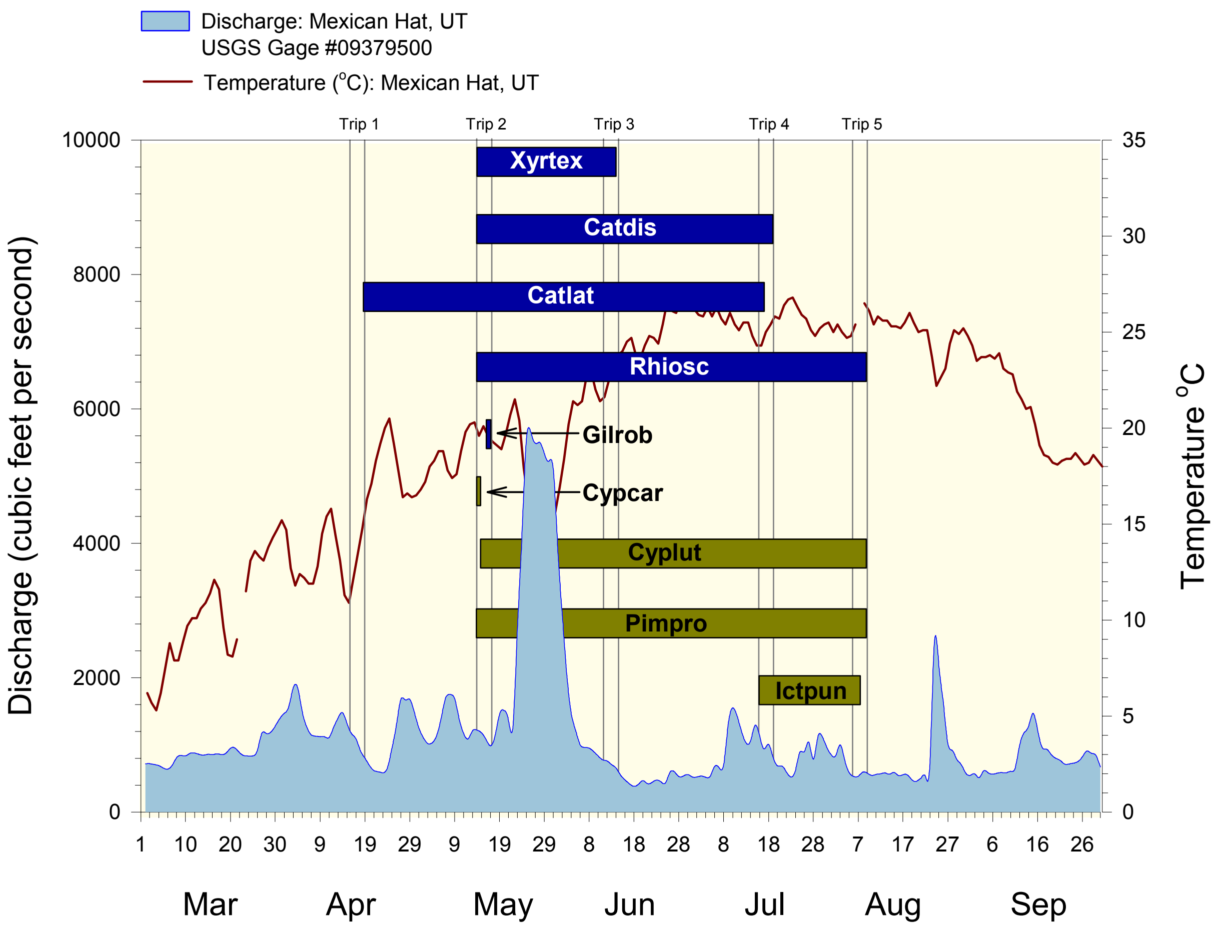


Figure 4. Occurrence of larval fishes in the San Juan River during 2012 plotted against discharge and water temperature. Bars represent the period between date of first and last collection of larvae for each species. Blue bars denote native species, yellow bars denote non-native species.

survey. The June survey was the last occurrence of larval razorback sucker. Larval captures of the other two catostomid species continued into the July survey (Figure 4). Larval common carp, *Cyprinus carpio*, red shiner, fathead minnow, *Pimephales promelas*, speckled dace, *Rhinichthys osculus*, and roundtail chub, *Gila robusta*, were first collected during the May survey. The collection of age-0 roundtail chub in 2012 marks the second consecutive year that this life-stage has been documented in the San Juan River. Age-0 roundtail chub were not collected between 1997 and 2010. All three catfish species encountered in 2012 were first collected during the July survey. There was no age-0 Colorado pikeminnow collected in 2012. A total of 114 age-1+ Colorado pikeminnow were collected in 2012. Age-1+ Colorado pikeminnow were encountered in each of the five survey months and are presumed to be result of augmentation efforts.

Isolated Pools

Catch data from isolated pools were not included in reach, month, yearly or between year analysis because capture efficiencies can be highly skewed in these habitats. During the 2012 larval survey, mean catch rate for all habitats, excluding isolated pools, was 322.6 fish per 100 m^2 (*SE* = 39.9). Mean catch rates in isolated pools sampled during the 2012 survey were over five times higher (1639.1 fish per 100 m^2, *SE* = 854.8). Isolated pools are closed systems and in the case of desiccating pools fishes are highly concentrated making for unusually high catch rates. Conversely, isolated pools that have desiccated to the point of nearly being dry, or have poor water quality (i.e. low dissolved oxygen) tend to contain few or no fish. This extreme variability in fish density is shown by the standard error for isolated pools in 2012 being an order of magnitude higher compared to other habitat types. Capture data from isolated pools is used in the larval occurrence graph and the calculation of frequency of occurrence as the variability in catch rates associated with this habitat type does not affect these metrics.

During the 2012 survey, 12 isolated pools were sampled in Reaches 1 and 2. These samples contained 2,441 age-0 specimens, nearly half of which were razorback sucker (*n* = 1,193). This number represents 67.1% of all age-0 razorback sucker collected in 2012.

2012 Trip Summary

The first survey trip took place between 16 - 19 April 2012. Mean daily discharge and water temperature during this period were 994 cfs and 14.2 ^{O}C. A total of 54 discrete habitats were sampled throughout the study area for a total effort of 1,407.5 m^2. The first collection of age-0 (flannelmouth sucker) fish occurred in Reach 3 at river mile 79.5. All age-0 fish (*n* = 20) collected during the April survey were flannelmouth sucker. Red shiner was the numerically dominant age-1+ species encountered (*n* = 516) followed by Colorado pikeminnow (*n* = 42). Red shiner was collected in each of the five reaches, with Colorado pikeminnow collected in Reaches 4-1.

The second larval survey (14 - 17 May 2012) took place a week before spring releases out of Navajo Dam. The mean discharge during the May survey was 1,117 cfs and the mean water temperature was 19.7 ^{o}C. A total of 67 collections were made producing 8,471 age-0 fish and encompassing 1,657.0 m^2 of habitat. Larvae of all three native suckers were collected during the May survey. Flannelmouth sucker had the highest mean catch rate of the three catostomid species (235.8 fish per 100 m^2 *SE* = 56.1) and was found in all five reaches of the study area. Bluehead sucker and razorback sucker were also collected in each of the five reaches with a mean of 213.7 (*SE* = 56.1) and 45.7 (*SE* = 20.1) fish per 100 m^2, respectively. The May survey also yielded the first larval common carp, fathead minnow, red shiner, roundtail chub, speckled dace, and western mosquitofish, *Gambusia affinis* (Figure 4).

The June survey (11 - 14 June 2012) took place after the descending limb of the spring hydrograph at a mean discharge of 725 cfs and mean water temperature of 22.8 °C. The 62 collections yielded 8,248 age-0 specimens in 8,428.0 m^2 of habitat sampled. This was the last month in which age-0 razorback sucker were collected. The three native catostomid species were encountered in each of the five reaches sampled. The June survey was the first month in which age-0 largemouth bass, *Micropterus salmoides*, was collected.

The fourth survey trip was conducted 16 - 19 July 2012. The mean daily discharge was 978 cfs and mean water temperature was 25.1 °C. The increase in mean daily discharge between the June and July surveys was a result of summer monsoonal rain events and not due to increased discharge from Navajo Reservoir. A total of 57 collections were made with 1,615.8 m^2 of habitat sampled. The July survey yielded more specimens (n = 9,286) than any of the other monthly surveys. Larval red shiner was distributed throughout the study area and was the numerically dominant species (n = 5,590). Age-0 channel catfish, *Ictalurus punctatus*, black bullhead, *Ameiurus melas*, yellow bullhead, *Ameiurus natalis*, and plains killifish, *Fundulus zebrinus*, were all first encountered during the July survey.

The August sampling survey was conducted from 6 – 9 August 2012. A total of 1,341.7 m^2 of habitat was sampled among 56 discrete collections. The survey took place immediately following a monsoonal related flow spike, with a mean discharge of 559 cfs and mean water temperature was 26.0 °C. Of the 1,683 age-0 specimens collected, 99.5% were non-native species. The only native species collected was speckled dace.

Endangered Species

Razorback sucker. The first collections of larval razorback sucker occurred on 14 May 2012 at multiple sites within the study area. The capture of larval razorback sucker at river mile 143.9 on this day represents the farthest documented upstream distribution of this species. The last age-0 razorback sucker collected was a single individual collected on 14 June 2012 in a pool habitat at river mile 3.4 (Figure 5).

A total of 1,778 age-0 razorback sucker were collected during the 2012 larval survey. The majority of these fish were collected in isolated pool habitats (n = 1,193). Between 1999 and 2012, isolated pools have had significantly higher catch rates than any other habitat type (F = 24.8, P < 0.0001, [Figure 6]). The river wide mean for razorback sucker was 10.3 fish per 100 m^2 (SE = 4.5). In 2012, 51 collections contained razorback sucker, resulting in a percent frequency of occurrence of 17.2% (Figure 7). Among trips, catch rates were significantly highest in May (F = 35.5, P < 0.0001, [Figure 8]). There were no significant differences among reaches. All of the 1,193 age-0 razorback sucker collected in isolated pools were found in Reaches 2 and 1.

From 1999 to 2012 annual mean catches of age-0 razorback sucker have varied. Catch rates in 2012 were significantly higher than eight of the twelve preceding years, and not significantly lower than any preceding year (F = 16.1, P < 0.0001, [Figure 9]). The combined monthly catch from 1999 to 2012 show May as having significantly higher catch rates than any other of the months in the study period (F = 150.6, P < 0.0001 [Figure 10]). Catch rates were significantly higher in Reach 1 compared to other reaches during the thirteen years of surveys (F = 24.3, P < 0.0001 [Figure 11]).

Age-0 razorback sucker collected in 2012 were almost entirely represented by larval fish (protolarvae to metalarvae) with the exception of 11 juvenile fish. Each of the ontogenetic stages encountered in 2012 was present in the study area during the month of May. The following month, all but protolarvae were collected (Figure 12). Protolarvae composed 1.2% of the age-0 razorback sucker collected during the 2012 survey and were only collected in the month of May

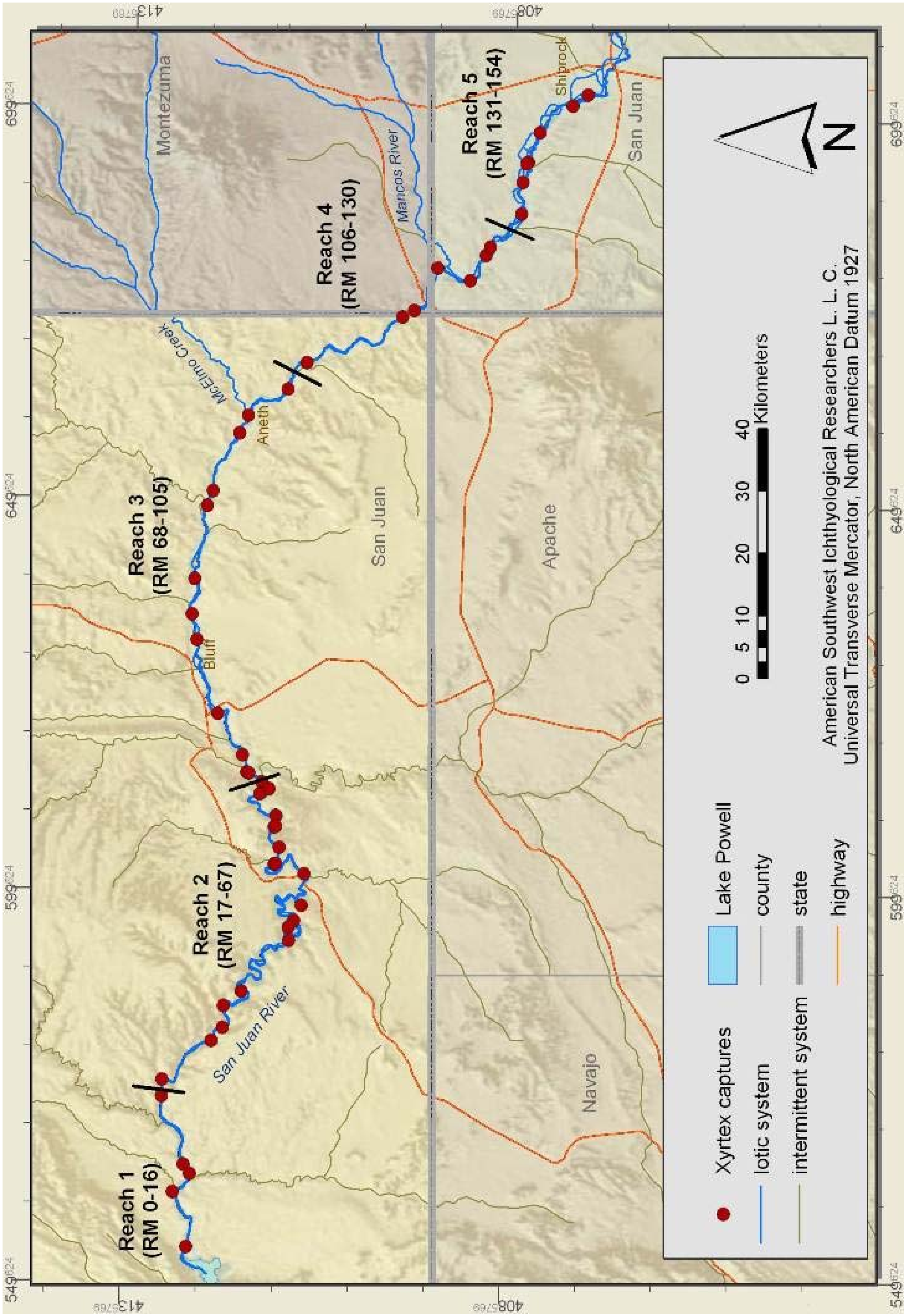


Figure 5. Map of the 2012 age-0 razorback sucker capture localities.

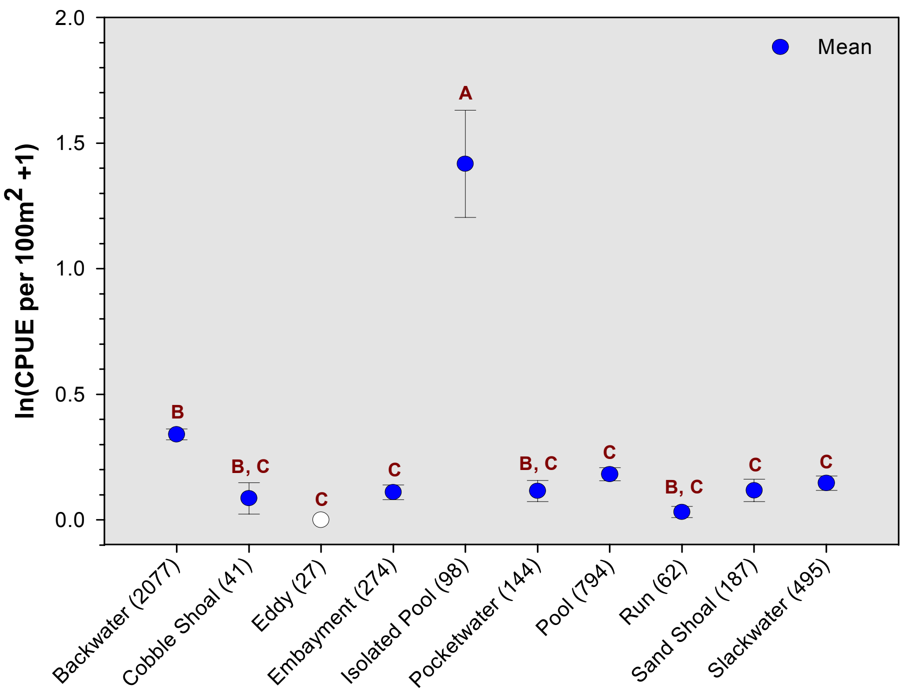


Figure 6. ln(CPUE per 100 m^2 +1) [+1 *SE*] for razorback sucker by habitat type sampled from 1999 to 2012. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicated that no fish were collected.

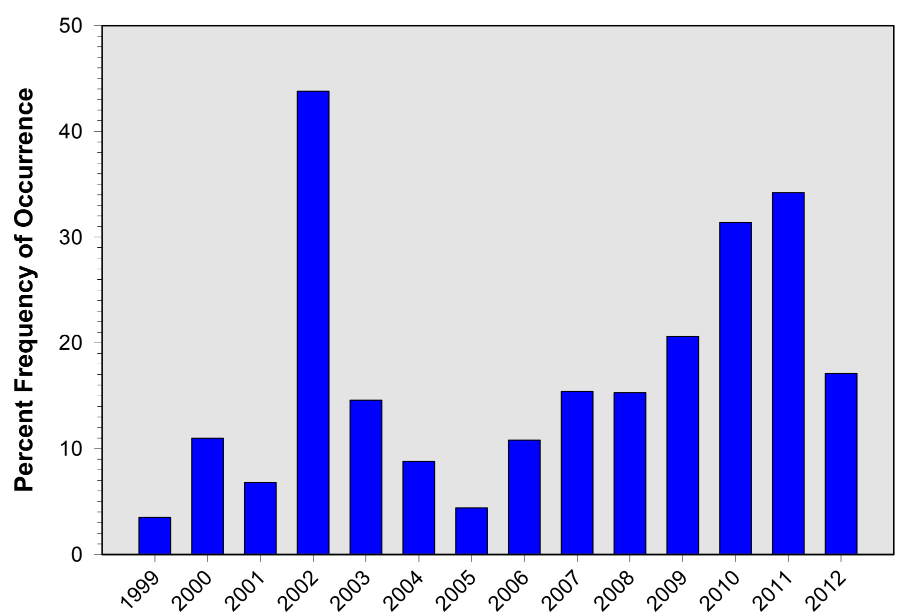


Figure 7. Percent frequency of occurence for razorback sucker from 1999 to 2012.

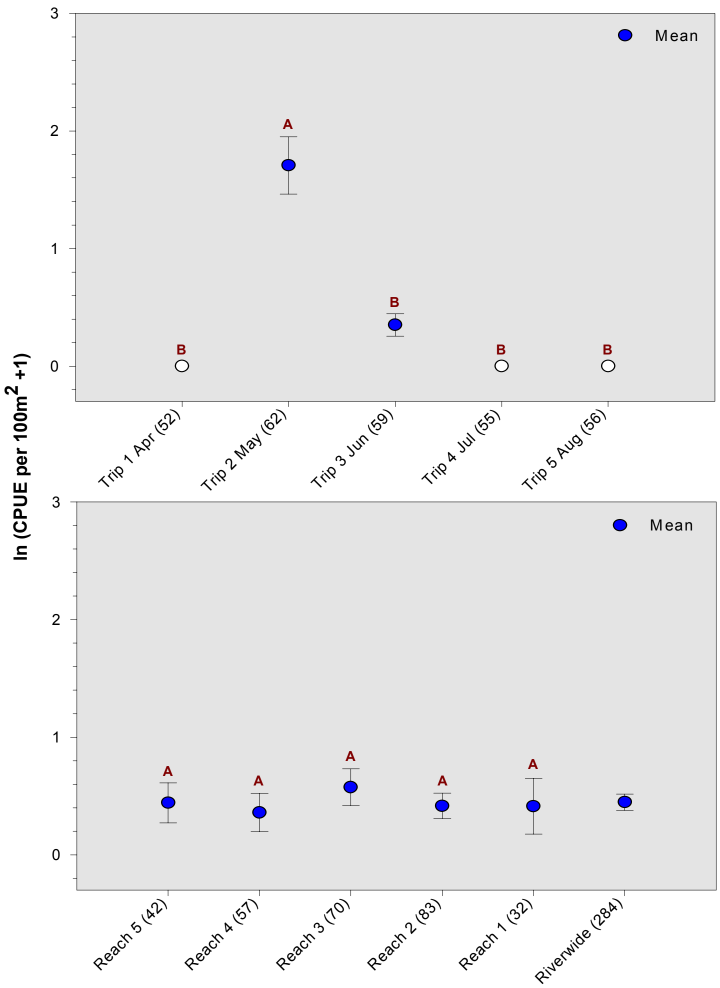


Figure 8. ln(CPUE per 100 m² +1) [+1 *SE*] for age-0 razorback sucker by trip (top graph), reach, and river wide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter were significantly different and open circles indicate that no fish were collected.

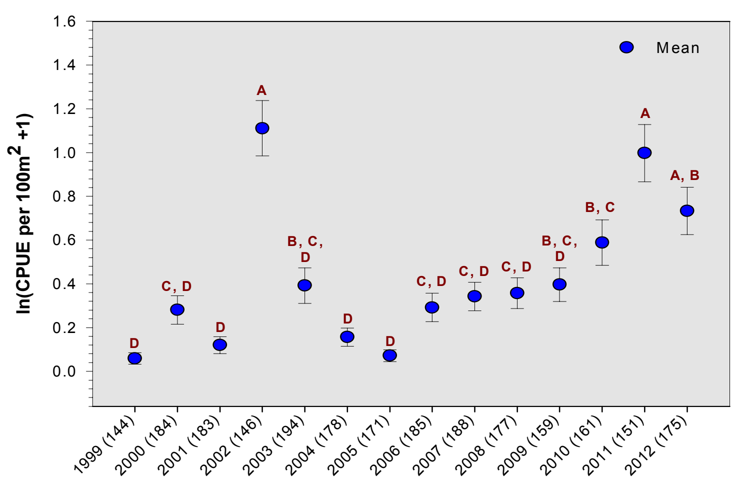


Figure 9. ln(CPUE per 100 m² +1) [+1 *SE*] for age-0 razorback sucker by year (April-June 1999-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

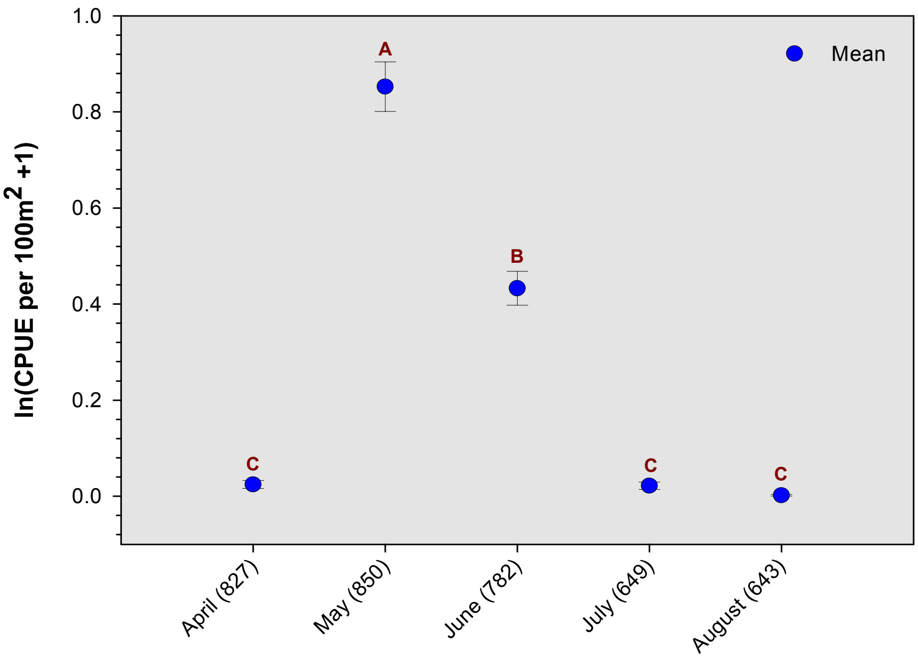


Figure 10. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 razorback sucker by month (April-June 1999-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

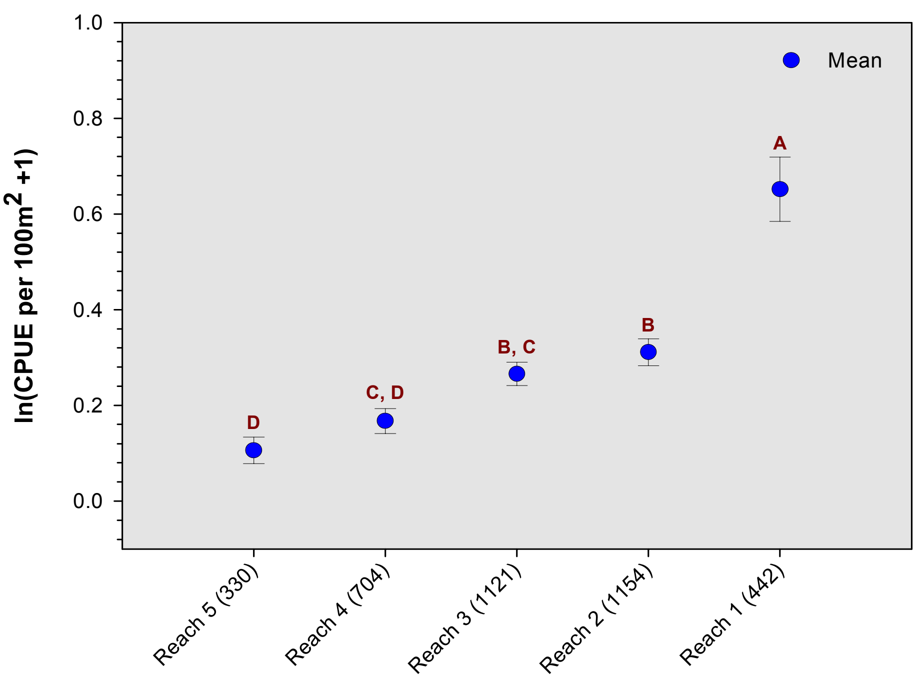


Figure 11. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 razorback sucker by reach (April-June 1999-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

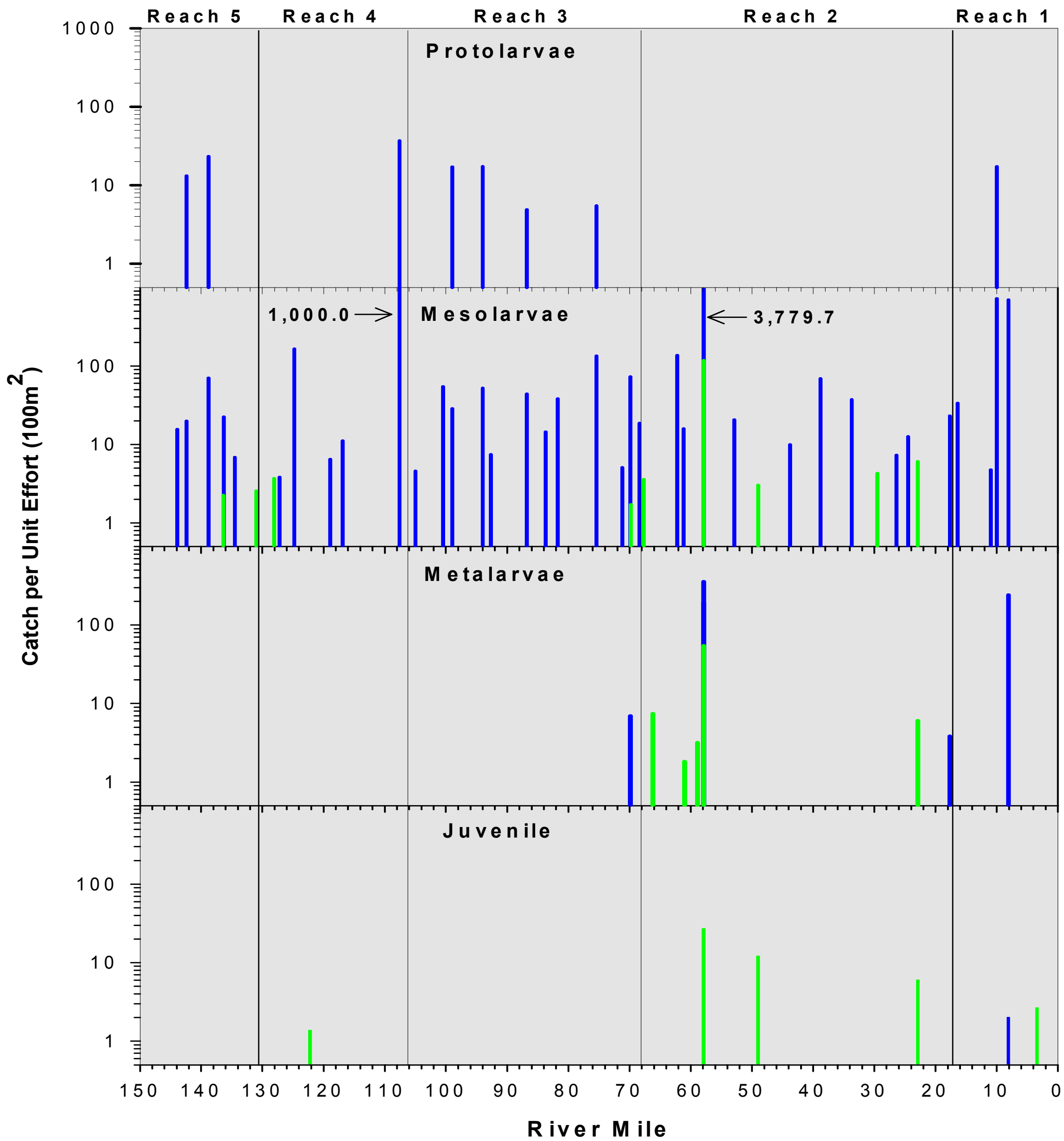


Figure 12. Catch per unit effort /100 m² of discrete ontogenetic stages (protolarvae, mesolarvae, metalarvae, and juvenile) of razorback sucker by sample locality during the 2012 survey. Blue bars represent May collections and green bars June collections.

(Figure 12). Unlike previous years, there was no clumped distribution of protolarvae within the study area. Clusters of protolarval captures can be used to infer upstream spawning areas. The majority (87.9%) of all razorback larvae collected in 2012 were mesolarvae which made up 88.8% of the May razorback sucker catch and 50.0% of the June catch. Mesolarvae were distributed throughout the study area. Metalarvae were collected at the downstream end of Reach 3, and in Reaches 2 and 1. Metalarvae made up 10.2% of the 2012 catch. Ten of the eleven juvenile fish were collected during the June survey. Juveniles were found primarily in Reaches 2 and 1, with a single specimen collected in Reach 4 at river mile 122.2, just downstream of the Mancos River confluence.

Back-calculated hatching dates for razorback sucker larvae (protolarvae and mesolarvae) collected during the 2012 larval survey indicate hatching occurred between 5 April and 5 June 2012 (Figure 13). Mean daily discharge and water temperature during this 69 day hatching period was 1,842 cfs and 17.1 ^{0}C. The range of discharge and temperature during this period was 584-5,650 cfs and 10.9-21.5 ^{0}C. Initial hatching of razorback sucker coincides with small spring discharge peaks that are the result of spring runoff coming from the Animas River. Hatching dates encompass the peak flow associated with releases from Navajo Reservoir, and end shortly after this discharge event.

Colorado pikeminnow. There were no age-0 Colorado pikeminnow collected during the 2012 larval fish survey. Prior to 2012, age-0 Colorado pikeminnow had been collected in three consecutive years (2009 - 2011) and in five of the eleven years (2002 - 2012) since the larval Colorado pikeminnow survey began using active (i.e. seines) instead of passive (i.e. drift-nets) sampling techniques (Figure 14). The low numbers of larval Colorado pikeminnow collected make meaningful statistical analysis difficult. Therefore numbers of larvae collected are noted for each year (Figure 14) rather than among year differences calculated through a one-way ANOVA analysis.

A total of 114 age-1+ Colorado pikeminnow were collected during in 2012; all presumably the result of augmentation efforts. Between 2003 and 2012, over 1,200 age-1+ Colorado pikeminnow have been collected during the larval fish surveys. Catch rates for age-1+ Colorado pikeminnow have cycled up and down with both 2006 and 2011 being years of relatively low abundance and 2009 and 2010 representing a peak in catch rates (F = 6.8, P < 0.0001 [Figure 15]).

Age-1+ Colorado pikeminnow collected in 2012 ranged in size from 42 - 140 mm TL (36 - 116 mm SL). During the April survey, 42 age-1+ Colorado pikeminnow were found in Reaches 4-1. The following month, 49 individuals were distributed throughout the study area. Combined, the April and May surveys produced 79.8% (n = 91) of the age-1+ Colorado pikeminnow collected in 2012. During the months of July and August, the few age-1+ Colorado pikeminnow collected were all found in Reach 1 (Figure 16).

Native Species

Speckled dace. Larval speckled dace were first collected during the May survey. Catch rates for this species peaked two months later during the July survey (F = 57.2, P < 0.0001 [Figure 17]). Speckled dace was collected in 47.3% of the 2012 collections making it the second most frequently encountered species. There was little statistical difference among reaches, with catch rates in Reach 5 only higher than those of Reach 1 (F = 3.8, P = 0.005 [Figure 17]). Among years, catch rates during 2012 were significantly higher than those of 2003, but no different than the period between 2004-2011(F = 6.6, P < 0.0001 [Figure 18]).

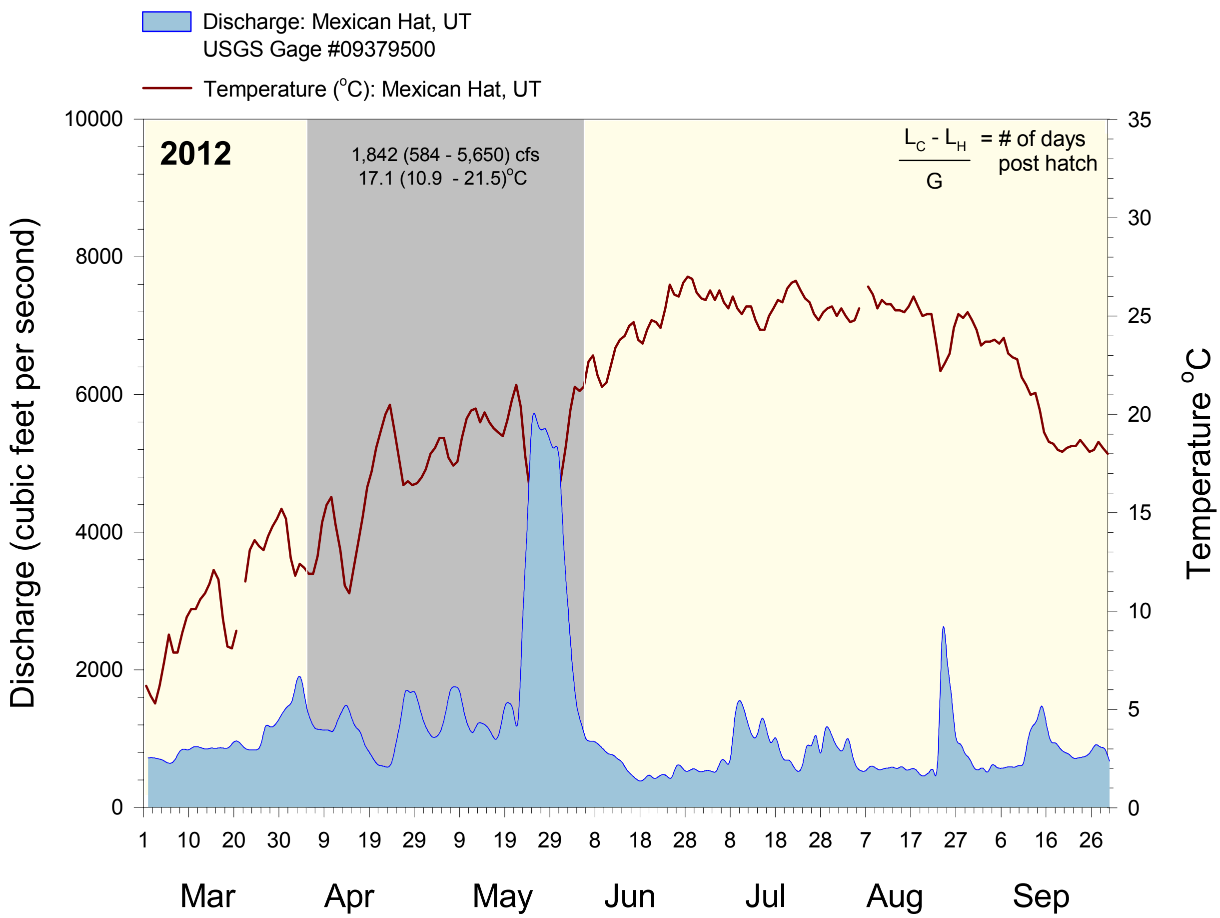


Figure 13. Back-calculated hatching dates for razorback sucker plotted against discharge and water temperature. Grey box delineates hatching period with mean (min max) discharge and water temperature reported.

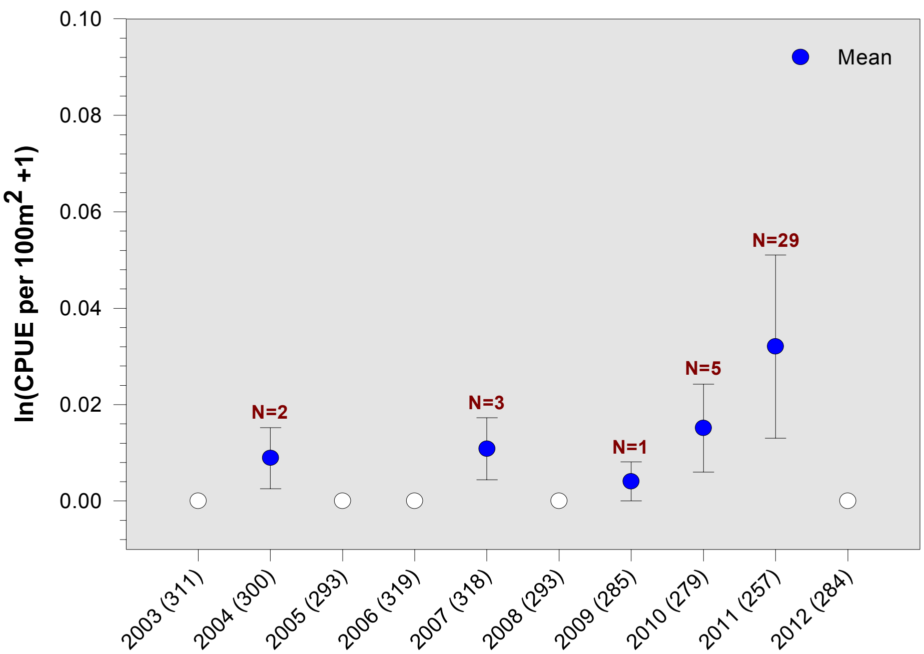


Figure 14. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 Colorado pikeminnow by year (2003-2012). Sample size reported on x-axis labels. Yearly totals of larvae collected listed above error bars. Open circles indicate that no fish were collected.

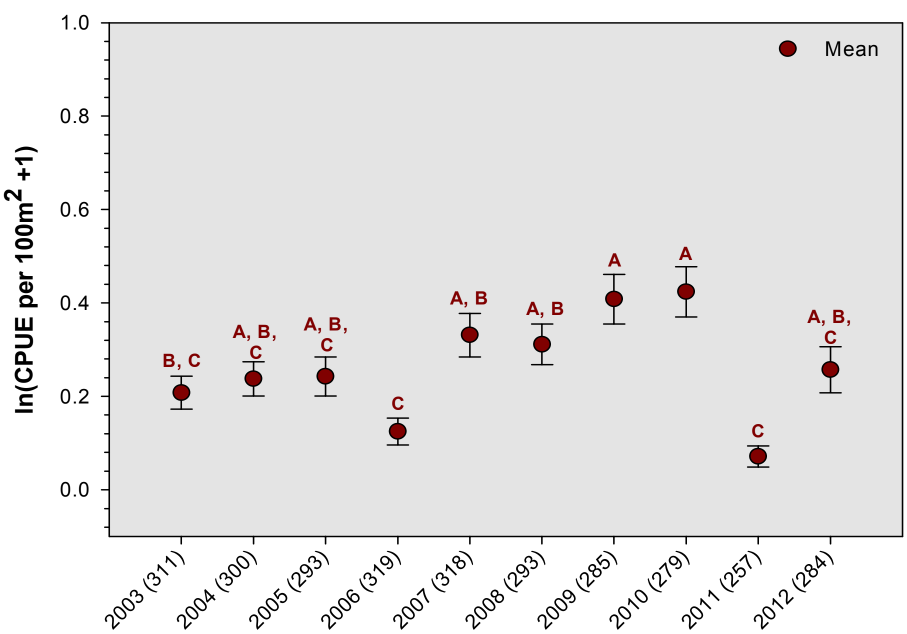


Figure 15. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-1+ Colorado pikeminnow by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

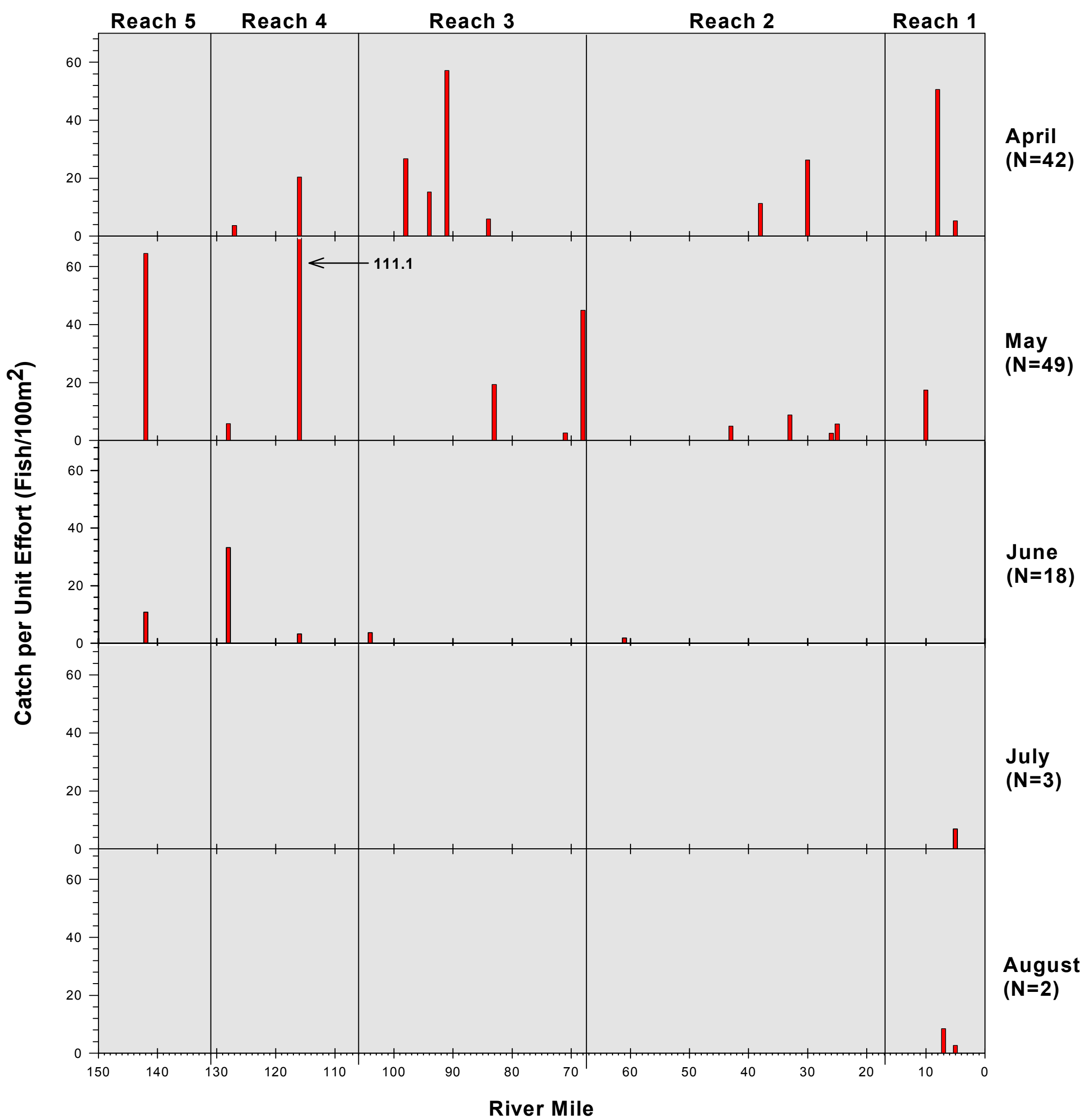


Figure 16. Catch per unit effort /100m^2 of age-1+ Colorado pikeminnow (N= 114) by sampling locality during the 2012 larval fish survey.

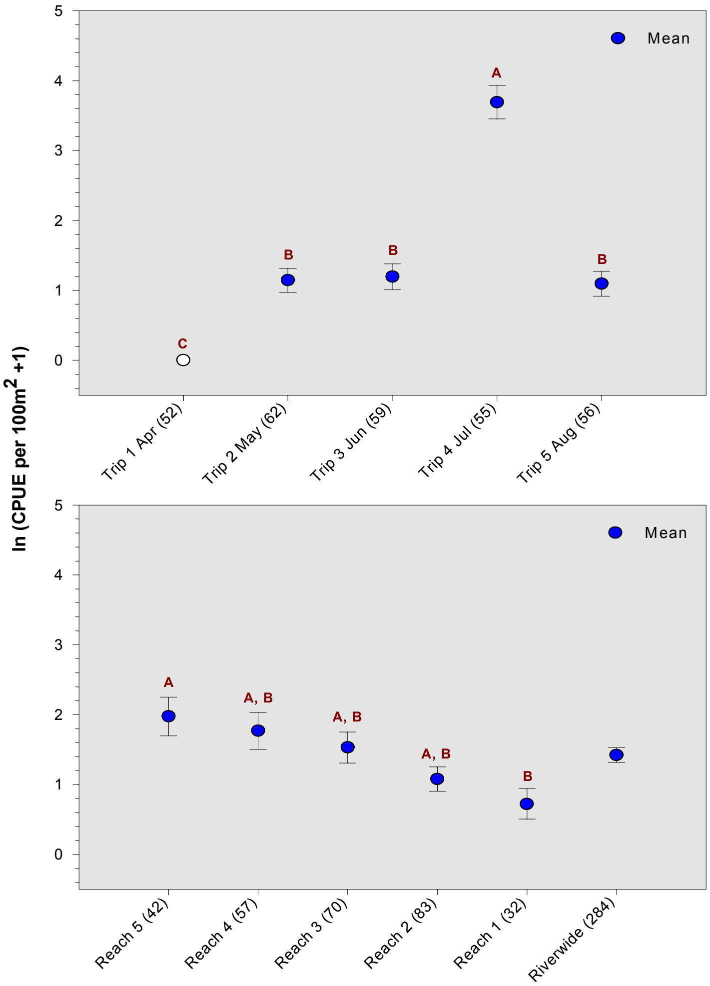


Figure 17. ln(CPUE per 100 m² +1) [+1 *SE*] for age-0 speckled dace by trip (top graph), reach, and river wide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

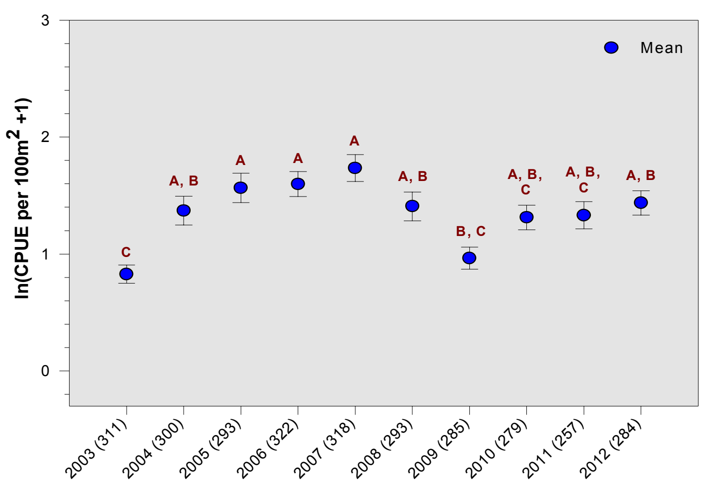


Figure 18. ln(CPUE per 100 m² +1) [+1 *SE*] for age-0 speckled dace by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

Flannelmouth sucker. Flannelmouth sucker was the most frequently encountered fish species during the 2012 larval fish surveys, occurring in 56.4% of collections. Overall, age-0 flannelmouth sucker composed 25.7% of the 2012 catch by number, and was the only age-0 species collected during the April survey. During the April survey, this species was distributed in Reaches 3-1 only. Catch rates of age-0 flannelmouth sucker were highest in May ($F = 77.9$, $P < 0.0001$ [Figure 19]) and had their greatest values in the three upstream (3-5) reaches of the study area ($F = 11.6$, $P < 0.0001$ [Figure 19]). The catch rate in 2012 was significantly higher than all of the preceding years except for 2007, 2008, and 2011 ($F = 12.1$, $P < 0.0001$ [Figure 20]).

Bluehead sucker. For the first time since this study began, bluehead sucker was the numerically dominant species collected in 2012. The 7,994 age-0 specimens collected is greater than the sum of age-0 bluehead sucker collected in the previous three years of the larval surveys. The first captures of larval bluehead sucker occurred during the May survey. Catch rates were highest in May and June ($F = 50.2$, $P < 0.0001$ [Figure 21]), and during these two months, bluehead sucker was present in nearly 80% of the collections. Among reaches, catch rates generally declined from upstream to downstream, with Reach 5 having significantly higher catch rates than all other reaches except Reach 4 ($F = 14.7$, $P < 0.0001$ [Figure 21]). Annual catch rates have a higher degree of variability compared to flannelmouth sucker, but the overall trend appears stable. Catch rates in 2012 were significantly higher than five of the nine preceding years ($F = 9.5$, $P < 0.0001$ [Figure 22]).

Non-Native Species

Red shiner. Red shiner was the numerically dominant and most frequently encountered non-native species in 2012. However, the 6,732 individual collected composed just 24.1% of the catch by number. During previous surveys, age-0 red shiner often accounted for greater than 50% of the total catch. A single red shiner was collected in an isolated pool at river mile 62.2 and was the only larval red shiner taken in May. This individual is represented in the larval occurrence graph (Figure 4) but, because isolated pools are not part of any trend analysis, it does not show up in the monthly catch rate figure. Catches of red shiner were highest in July and August ($F = 68.0$, $P < 0.0001$ [Figure 23]). Among reaches there was no significant difference in catch rates ($F = 2.2$, $P = 0.0682$ [Figure 23]): however Reaches 3 and 4 accounted for over 80% of the catch by number. The 2012 catch rate was lower than five of the nine preceding years and was among the lowest recorded for this species ($F = 12.2$, $P < 0.0001$ [Figure 24]).

Common carp. As has been the case for the last 10 years, densities of age-0 common carp in the San Juan River were low in 2012. With just 53 individuals collected, this species represented only 0.2% of the total catch. Larval common carp were first collected in May, not encountered in June, and only juveniles collected in July (Figure 25). This species was found in Reaches 2 and 3, with no significant differences in catch rates among reaches ($F = 1.2$, $= 0.302$) or months ($F = 0.9$, $P = 0.480$ [Figure 25]). The 2012 catch rate was not different than five of the nine preceding years ($F = 9.1$, $P < 0.0001$ [Figure 26]): however the 53 individuals collected in 2012 is one of the lowest numeric totals recorded in the last ten years.

Fathead minnow. Larval fathead minnow were first encountered during the May survey in three localities. The following month fathead minnow remained rare in the San Juan River, but were distributed throughout the study area by the July survey. Catches of fathead minnow were

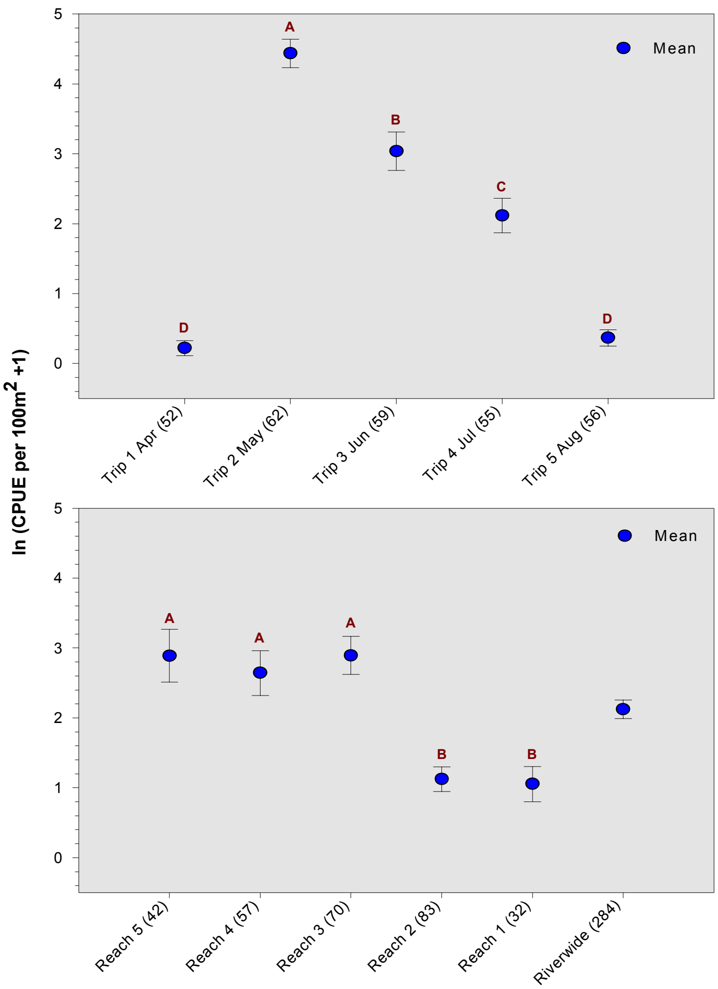


Figure 19. ln(CPUE per 100 m² +1) [+1 *SE*] for age-0 flannelmouth sucker by trip (top graph), reach, and river wide (bottom graph) for 2012. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

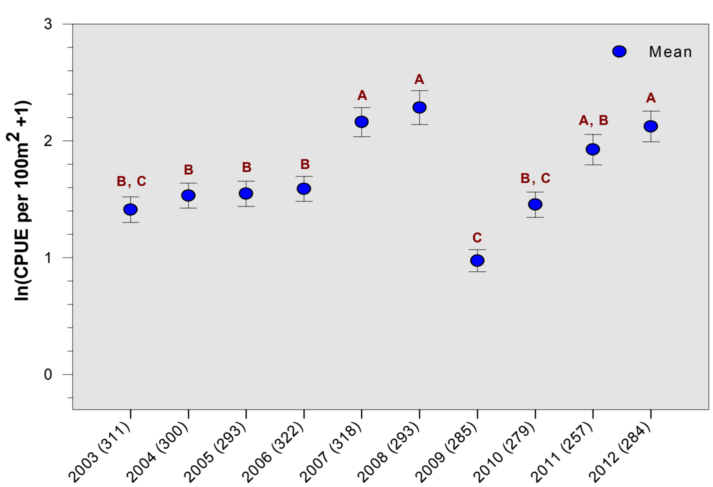


Figure 20. ln(CPUE per 100 m² +1) [+1 *SE*] for age-0 flannelmouth sucker by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

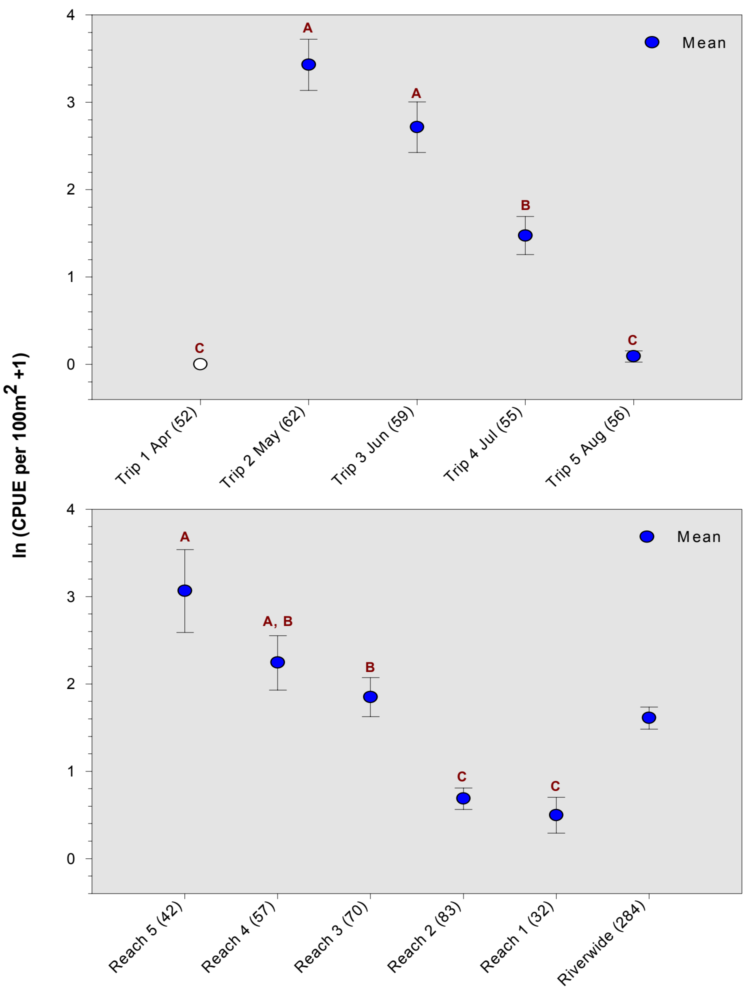


Figure 21. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 bluehead sucker by trip (top graph), reach, and river wide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

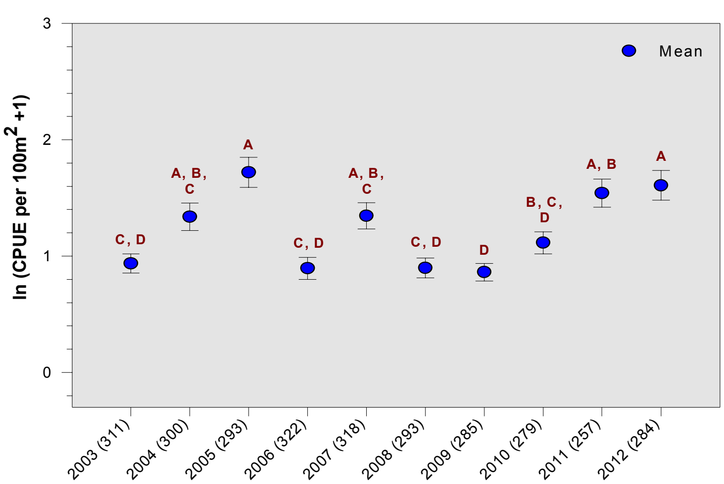


Figure 22. ln(CPUE per 100 m^2 +1) [+1 *SE*] for age-0 bluehead sucker by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

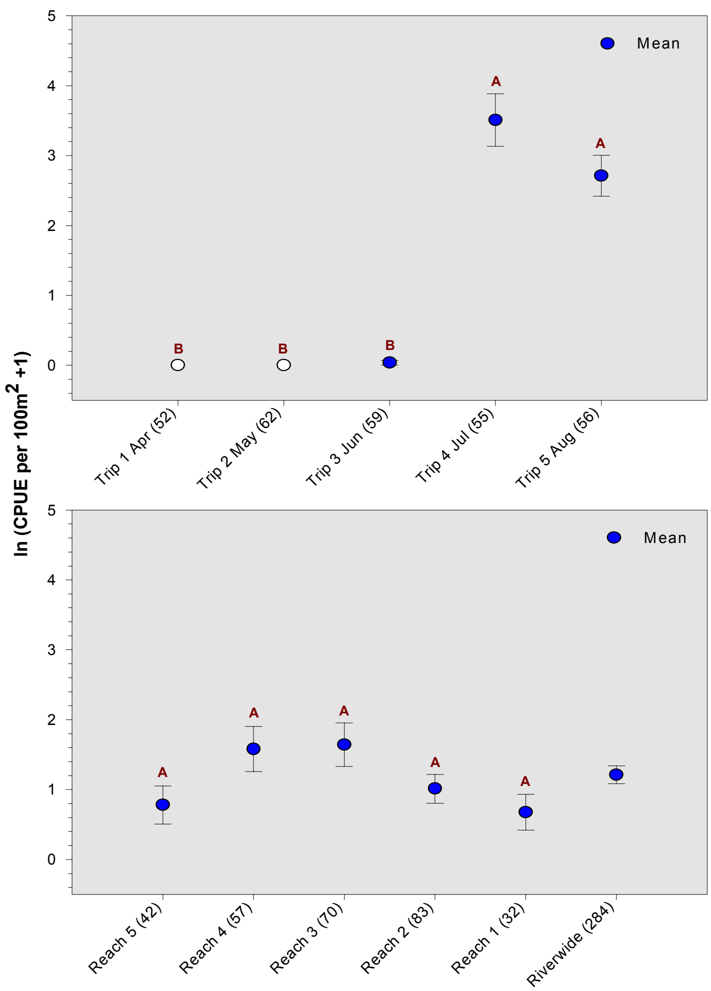


Figure 23. ln(CPUE per 100 m² +1) [+1 *SE*] for age-0 red shiner by trip (top graph), reach, and river wide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

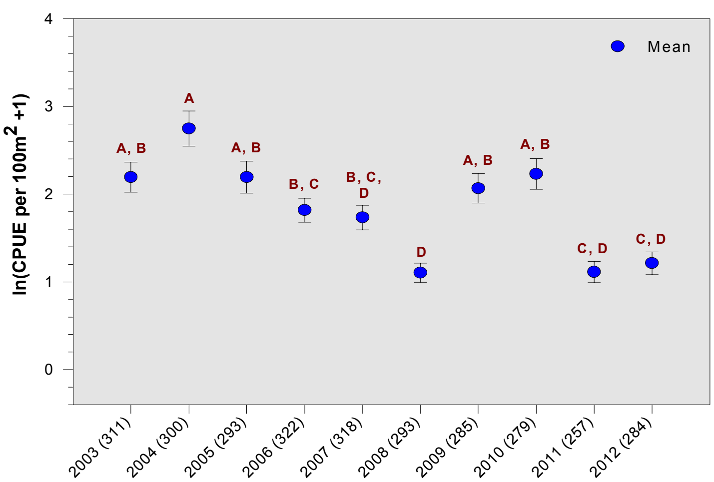


Figure 24. ln(CPUE per 100 m² +1) [+1 *SE*] for age-0 red shiner by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

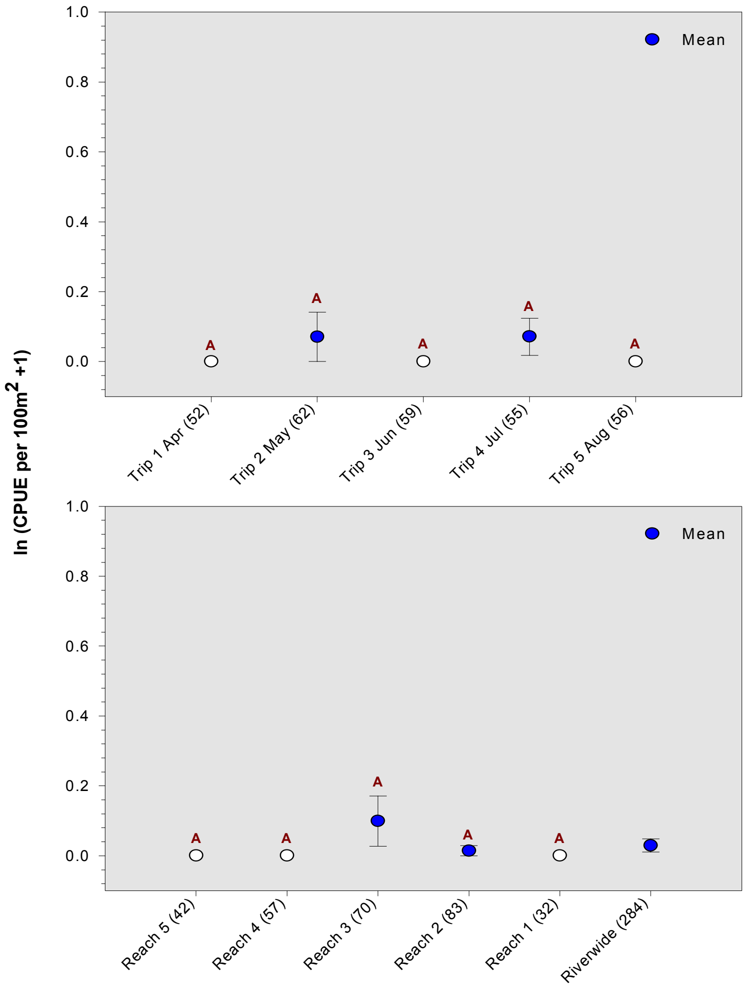


Figure 25. ln(CPUE per 100 m^2+1) [+1 *SE*] for age-0 common carp by trip (top graph), reach, and river wide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

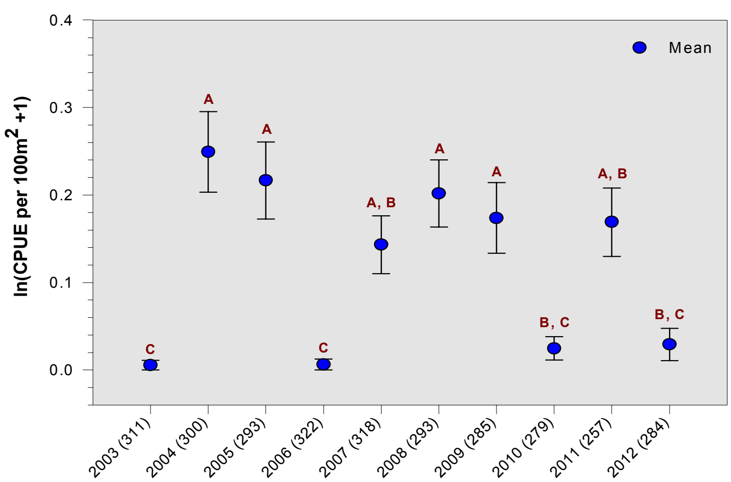


Figure 26. ln(CPUE per 100 m^2+1) [+1 *SE*] for age-0 common carp by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

significantly higher in the two upstream reaches (4 and 5) compared to Reaches 2 and 1 (F = 6.2, P < 0.0001 [Figure 27]). Annual catch rates of fathead minnow have been declining since 2003 with the lowest catch of age-0 individuals occurring in 2009 (Figure 28). The catch rate in 2012 is only significantly higher than those observed in 2009 (F = 30.8, P < 0.0001).

Channel catfish. Similar to previous larval fish surveys, this species was first collected in July and was found in each of the five reaches (Figure 29). The following month, this species was not found in Reach 5, but was in each of the four subsequent downstream reaches. Catch rates in Reach 5 were significantly lower than those of Reaches 2 and 1 (F = 2.8, P = 0.0271 [Figure 29]). Among years, the channel catfish catch in 2012 was similar to seven of the last nine years. Densities in 2012 were significantly higher than those of 2004 and lower than 2007 (F = 12.9, P < 0.0001 [Figure 30]).

Native and Non-Native Catch

From 2003 to 2012, the proportions of age-0 native and non-native catches have varied. Prior to 2007 there were no significant differences between densities of native and non-native fishes. Beginning in 2007, there was an increasing trend in the native fish catch and a decline in the non-native fish catch (Figure 31). These trends appear to be driven by the spawning efforts of non-native red shiner, and the common natives, flannelmouth sucker and speckled dace. Catch rates of native fishes were significantly higher than those of non-natives (F = 15.6, P < 0.0001) for both 2007 and 2008. The following year, the catch of non-native fishes rose primarily because of an increase in red shiner and fathead minnow larvae and native fishes declined primarily as a consequence of decreases in flannelmouth sucker. Finally, during the 2011 and 2012 surveys, native catch rates were once again significantly higher than those of non-native species. During these years both flannelmouth and bluehead sucker catch rates increased while red shiner catch rates decreased.

Monitoring Sites

During the 2012 survey, each of the monitoring sites (Table A-1, Figure 3) was visited each month. The site was sampled if suitable nursery habitat was available, otherwise photographs were taken and conditions noted on a field data sheet. During 75 visitations to the monitoring sites (15 sites x five monthly surveys), a backwater habitat was encountered 10 times, isolated pools were found 23 times, with the remaining 42 visitations being to dry sites. Most (n = 7) of the backwaters encountered were in Reach 4, with one in Reach 2 and two in Reach 1. These backwater samples contained 2,881 age-0 fishes, of which 38 were razorback sucker. Of the 23 isolated pool encounters, on nine occasions the site was deemed suitable for sampling. All of the isolated pool samples were made in Reaches 2 and 1. These collections contained 2,337 specimens, of which 1,176 were razorback sucker.

Only two of the monitoring sites were found to be backwater habitats for two consecutive monthly surveys. Cowboy Wash at river mile 116.9 was a backwater in April and May while the site at river mile 118.5 was a backwater in May and June. The lack of connectivity in 2012 contrasts sharply with the 2011 monitoring site results. During 2011, nearly half of all monitoring sites maintained a connection to the main channel between the months of May and July.

RERI Sites

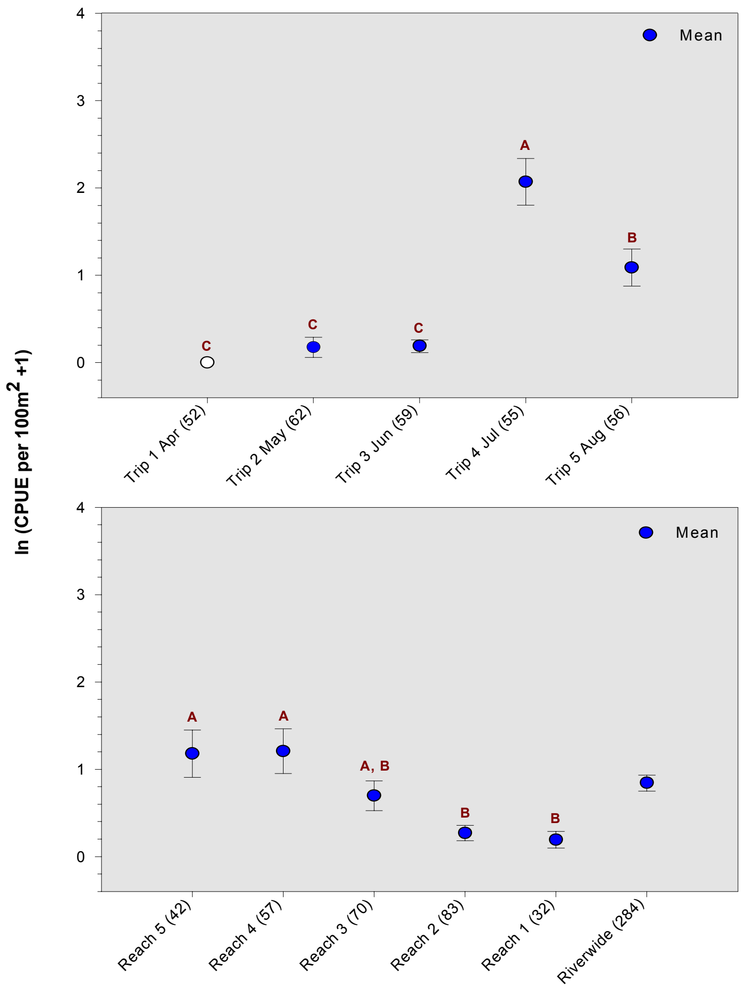


Figure 27. ln(CPUE per 100 m^2+1) [+1 *SE*] for age-0 fathead minnow by trip (top graph), reach, and river wide (bottom graph) during the 2012 survey. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

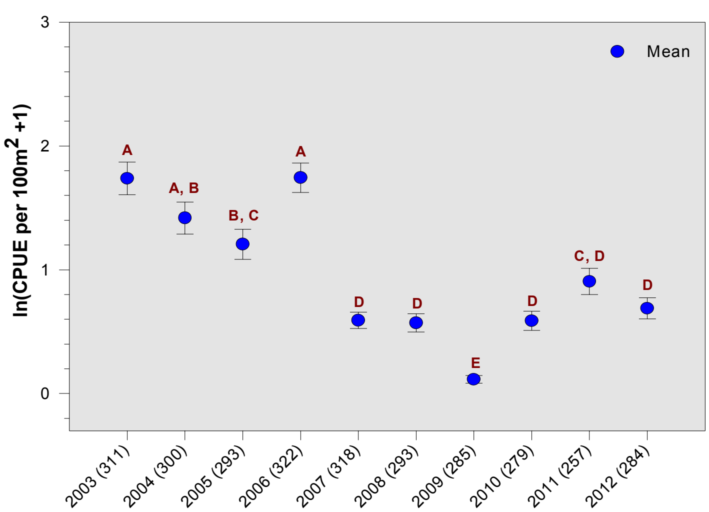


Figure 28. ln(CPUE per 100 m^2+1) [+1 *SE*] for age-0 fathead minnow by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

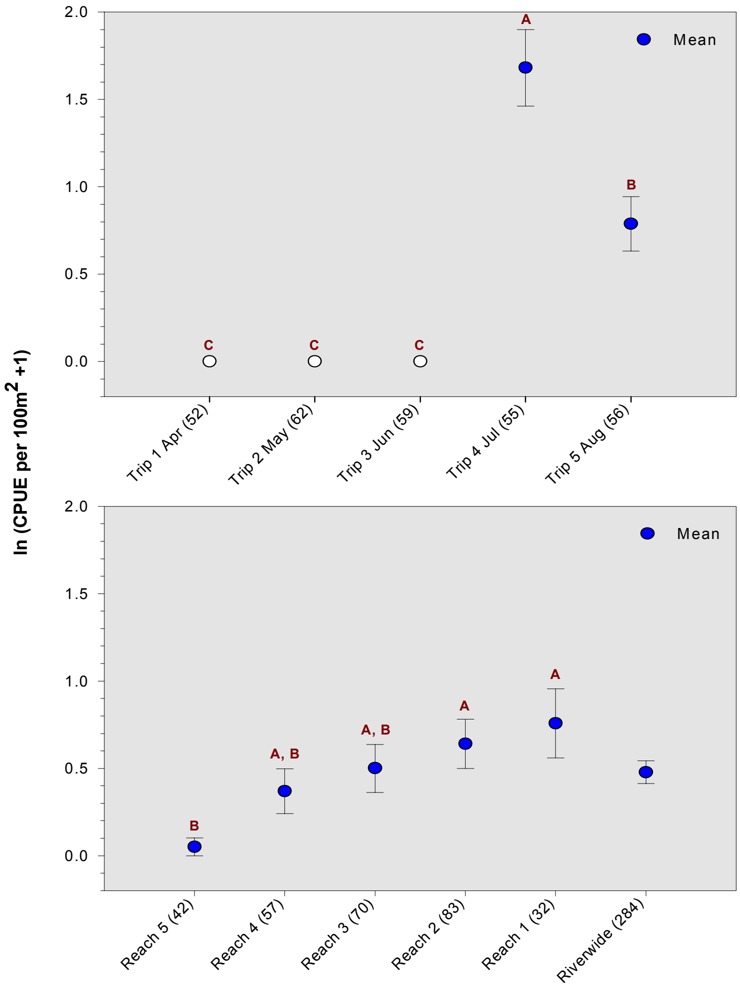


Figure 29. ln(CPUE per 100 m² +1) [+1 *SE*] for age-0 channel catfish by trip (top graph), reach, and river wide (bottom graph) during the 2012 survey. Sample size reported on x-axis labels. Means not connected by the same letter are significantly different and open circles indicate that no fish were collected.

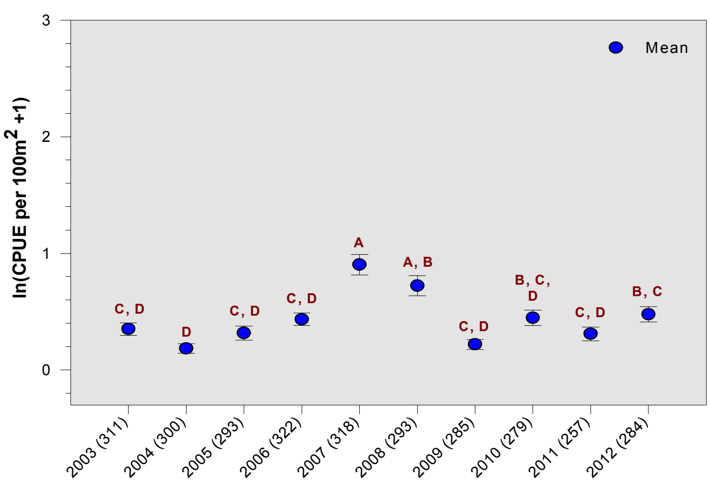


Figure 30. ln(CPUE per 100 m² +1) [+1 *SE*] for age-0 channel catfish by year (2003-2012). Sample size reported on x-axis labels. Means not connected by the same letter are significantly different.

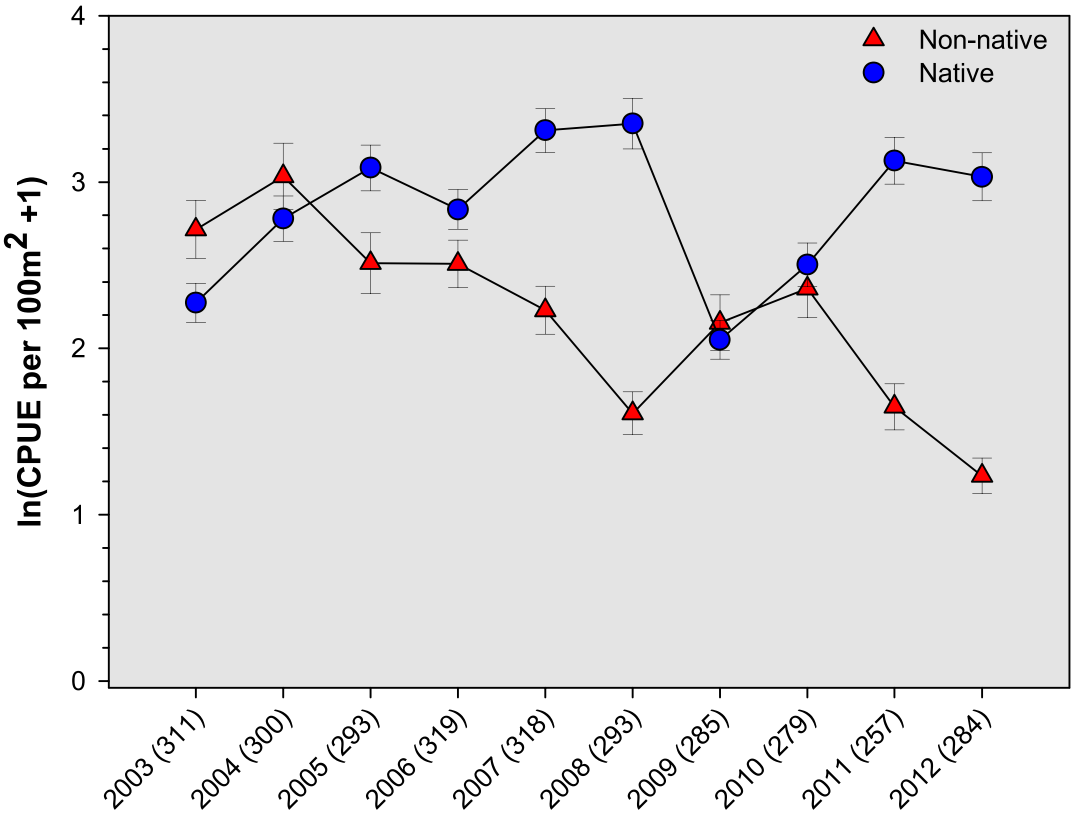


Figure 31. ln(CPUE per 100 m^2 +1) [+1 *SE*] of non-native taxa and native taxa from 2003-2012. Sample size reported on the x-axis labels.

During the 30 RERI site visitations (six sites x five monthly surveys), 26 collections were made. A total of 3,029 age-0 specimens representing 10 species were collected (Table 4). Over half (*n* = 1,559) of these fishes were collected from the most upstream RERI site located at river mile 132.2. Two of the RERI sites contained razorback sucker. One razorback sucker was captured during the May survey at the river mile 127.2 site, and the other collected during the June survey at the river mile 128.6 site (Table 4). Among all RERI sites, 82.3% (*n* = 2,495) of the fish collected were native species. In addition, 11 age-1+ Colorado pikeminnow were also collected in the RERI sites.

Discussion

The 1,778 age-0 razorback sucker collected in 2012 represents the largest numeric total for this species during the tenure of this study. For three consecutive years, more than 1,000 age-0 razorback sucker have been collected from the San Juan River. This three-year period (2010 - 2012) has produced two-thirds (63.7%) of all razorback sucker collected from the San Juan River in the last 15 years. This fact, coupled with a continued increase in the upstream distribution of larvae, a nearly 10 week spawning period and 15 consecutive years of documented reproduction all suggest that adult razorback sucker are well established in the San Juan River.

The collection of nearly 1,200 razorback sucker from isolated pools makes the interpretation of the 2012 results difficult. While razorback sucker larvae have been collected from isolated pools in previous years, those collections account for a relatively small percentage of razorback sucker captures. The only other year in which razorback sucker larvae were collected in appreciable numbers from this habitat type was 2010, with over 25% (*n* = 322) of the 1,251 razorback sucker collected found in isolated pools. Both 2012 and 2010 were similar in both mean discharge (*n* = 1,287 and 1,552 cfs respectively) and range of discharge (383 - 5,650 and 488 - 5,280 cfs respectively) during the study period.

Two samples made in isolated pool habitats accounted for 1,147 of the 1,778 age-0 razorback sucker collected in 2012. One of those collections was made in one of the monitoring sites established at river mile 57.9 (Lime Creek) just upstream of Mexican Hat, Utah. On May 15th, 679 razorback sucker were collected in just 19.3 m^2 of habitat sampled. W. Howard Brandenburg recorded in his field note that a “substantial sand berm” isolated this habitat from the main channel. With a maximum recorded water depth of 17 cm, midday temperatures measured at 28°C, and dissolved oxygen levels of water recorded at about half of those found in main channel habitats, survival of these individuals within this habitat for a prolonged period of time seems unlikely. Mean discharge at the time of collection was 1,180 cfs at Mexican Hat. Discharge did not increase substantially for nine more days. On May 24th mean discharge was recorded at 4,090 cfs and peaked two days later at 5,650 cfs (the highest recorded value in 2012). This habitat likely reconnected to the main channel but the survival of any larvae is unknown. The following month (June) this site still contained an isolated pool, but had completely dried out by July and remained dry in August. This same pattern was observed for many of the monitoring sites that contained isolated pools in the month of May (Table A-6). While many factors can affect the discharge necessary to inundate a paticular monitoring site, data from 2011 and 2012 suggest that most sites are connected to the main channel at flows of 1,200 cfs and greater and nearly all are completely dry at flows of 550 cfs and less (Table A-6).

The second isolated pool collection to produce numerous larval razorback sucker also occurred at a monitoring site located at river mile 8.1 (Steer Gulch). On May 17th, a total of 468 individuals were collected in 49.7 m^2 of habitat sampled. The physical characteristics of this site differ than those found at Lime Creek. While the sustrata in Lime Creek is primarily bedrock, the

RERI Site (RM)	Month	Habitat Type		CYPLUT	PIMPRO	RHIOSC	CATDIS	CATLAT	XYRTEX	AMEMEL	ICTPUN	GAMAFF	MICSAL
127.2	April	Pool											
	May	Pool						5	1				
	June	Run					2	2					
	July	Slackwater		48	20	64	2	29		1	6	6	
			Total	**48**	**20**	**64**	**4**	**36**	**1**	**1**	**6**	**6**	
128.6	April	Pool											
	May	Pool				9	92	317					
	June	Sand Shoal				13	21	10	1				1
	July	Slackwater		135	44	63	50	14				8	
	August	Backwater		34	122		2					32	
			Total	**169**	**166**	**85**	**165**	**341**	**1**			**40**	**1**
132	April	Sand Shoal											
	May	Sand Shoal						3					
	June	Run				1	12	11					
	July	Slackwater		1	2	3		2			2	3	1
	August	Sand Shoal			16							3	
			Total	**1**	**18**	**4**	**12**	**16**			**2**	**6**	**1**
132.2	April	Pool											
	May	Pool				5	175	55					
	June	Pool				24	780	367					
	July	Slackwater		21	14	70	23	24				1	
			Total	**21**	**14**	**99**	**978**	**446**				**1**	
130.7A	April	Sand Shoal											
	May	Sand Shoal					10	10					
	June	Run				12		18					
			Total			**12**	**10**	**28**					
130.7B	April	Pool											
	May	Sand Shoal						12					
	June	Slackwater			1	3	92	62					
	July	Slackwater			3	21	3				1	3	
	August	Cobble shoal		4	1								
			Total	**4**	**5**	**24**	**95**	**74**			**1**	**3**	

Table 4. Species composition (age-0 fishes) and habitat type (at time of sampling) of the six RERI sites sampled during 2012.

substrata in Steer Gulch is primarily sand due to the influence of Lake Powell. In previous years, isolated pools in this lateral canyon have been noted to persist between monthly sampling surveys in the absence of any appreciable rise in river discharge between months. The sand substrate may be much more conducive to the maintenance of an isolated pool through interstitial flow. Often, the isolated pools found in this canyon can extend well over 100 m up the canyon. At the time of visitation, maximum water depth was measured at 29 cm, and dissolved oxygen levels were the same as those found in the main channel. In the field data sheet, researcher Steven Zipper noted a tenuous (measured in millimeters) narrow (measured in centimeters) patch of water connecting this site to the main channel suggesting any rise in discharge would likely reconnect this isolated pool to the main channel. While this “connection” (essentially a patch of very wet sand) to the main channel was noted, the site was deemed to function as an isolated pool, with fish movement in and out of the site not possible. The flow spike that began one week after the time of visitation likely inundated this side canyon. While the survival of fish within the isolated pool cannot be known, the large size of the habitat suggests desiccation prior to reconnection was unlikely.

The uncertainty of survival of razorback sucker in isolated pools requires removal of this habitat type from all trend analysis. However, information from these habitat types is factored into the frequency of occurrence for any given species. The collection of multiple ontogenetic stages of larvae within isolated pools is indicative of the duration of spawning events and collection of protolarval specimens still suggests the presence of spawning areas relatively close upstream.

The absence of any larval Colorado pikeminnow in the 2012 larval survey collections, coupled with the fact that just 40 larval specimens have been collected in the last 10 years, suggests relatively few reproducing adults within the San Juan River. The absence of age-0 specimens does not mean an absence of reproduction by Colorado pikeminnow, but that 2012 reproductive efforts may have been below the detection level of this study. The 2008 data point for this species may support this hypothesis. Larval Colorado pikeminnow were collected in 2007 and 2009. The fact that this species is long lived and that reproductively mature fish are not being stocked into the San Juan River, suggests that some number of reproductively viable fish *existed* in the San Juan River during 2008. Therefore the most parsimonious explanation of why no larvae were collected in 2008 (given the presence of larvae in 2007 and 2009) is that the spawning efforts of this species were below detection limits. The alternative explanations (i.e. no spawning by adults, or complete mortality of eggs) seems unlikely.

Although larval Colorado pikeminnow remain rare, the collection of larvae for three continuous years between 2009 and 2011 is encouraging. Large scale yearly augmentation of juvenile age-0 Colorado pikeminnow into the San Juan River began in 2002. Prior to that, between 1996 and 2001, a series of opportunistic and experimental stockings did take place. These stockings primarily consisted of a limited number of adult fish, or thousands of larval fish. Assuming sexual maturity at age-6, age-0 fish stocked into the river in 2002 would not be mature until 2008; fish stocked in 2003 mature in 2009 and so on. The collection of larvae between 2009 and 2011, coupled with more adult captures by other reasearchers in recent years, may suggest that individuals from those early stocking years are beginning to recruit into the adult population and reproduce.

The six RERI sites on the San Juan River represent a new approach to endangered species recovery. Prior to the completion of these sites in late 2011, targeted mechanical restoration of habitats had not been done within the tenure of the recovery program. While each of these sites were sampled during 2012, little information can be gleaned from the species composition found after just one year of data collection. The more salient point to these collections comes from the fact everytime an RERI site was sampled, larval fish were collected. The collection of larval fish from any habitat type, at any time of the year is never certain. Many backwaters, pools, and other low velocity habitats have produced no larval specimens throughout the past 15 years of this study. Whether it was a result of favorable hydrologic conditions that moved larvae into these habitats, nursery habitat that was of excellent quality, or a combination of both, these sites maintained age-0 specimens within them between May and August of 2012. Only time will tell if these sites maintain their connection to the main channel, and continue to provide nursery habitat to larval fishes. What is certain is that more mechanical restoration of habitats will be done in the near future in an effort to further the recovery of Colorado pikeminnow and razorback sucker in the San Juan River.

Acknowledgments

Numerous individuals assisted with the efforts necessary to accomplish this project. Jennifer L. Hester, Bruce Christman, S.A. Zipper and Scott L. Durst (USFWS). This project benefited from the invaluable logistical assistance of Ernie Teller (USFWS). Assistance with all aspects of collection, database management and curation was provided by Alexandra M. Snyder (UNM, MSB). Collections were prepared for identification and curation by Sarah J. Sasek, Kylie R. Naegele, and Maribel Solis (UNM, MSB). Dr. Robert K. Dudley provided analytical and technical support. Dr. Stephen T. Ross, Dr. Mel Warren, and Scott L. Durst reviewed and commented on earlier drafts. This study was approved by the San Juan River Basin Biology Committee through the San Juan River Basin Recovery Implementation Program and funded under a U. S. Bureau of Reclamation, Salt Lake City Project Office Award # 07-FG-40-2642 administered by Dr. Mark C. McKinstry and Melynda Roberts (U.S. Bureau of Reclamation). The collecting of fish was authorized under scientific collecting permits provided by the Utah Division of Wildlife Resources, New Mexico Department of Game and Fish, U.S. Fish and Wildlife Service, and Navajo Nation.

Literature Cited

Auer, N. A. (ed.). 1982. Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. Great Lakes Fishery Commission, Ann Arbor, MI 48105. Special Publication. 82-3: 744 pp.

Behnke, R. J., and D. E. Benson. 1983. Endangered and threatened fishes of the upper Colorado River Basin. Colorado State University, Cooperative Extension Service Bulletin 503A, Fort Collins, CO.

Bestgen, K. R., 1996. Growth, survival, and starvation resistance of Colorado squawfish larvae. *Environmental Biology of Fishes* 46:197-209.

Bestgen, K. R., 2008. Effects of water temperature on growth of razorback sucker larvae. *Western North American Naturalist* 68:15-20.

Bestgen, K. R., and D. W. Beyers. 2006. Factors affecting recruitment of young Colorado pikeminnow: synthesis of predation experiments, field studies, and individual-based modeling. *Transactions of the American Fisheries Society* 135:1722-1742.

Bestgen, K. R., R. T. Muth, and M. A. Trammell. 1998. Downstream transport of Colorado squawfish larvae in the Green River drainage: temporal and spatial variation in abundance and relationships with juvenile recruitment. Unpublished report to the Colorado River Recovery Implementation Program: Project Number 32. 63 pp.

Bestgen, K. R., G. B. Haines, R. Brunson, T. Chart, M. A. Trammell, R. T. Muth, G. Birchell, K. Christopherson, and J. M. Bundy. 2002. Status of wild razorback sucker in the Green River Basin, Utah and Colorado, determined from basinwide monitoring and other sampling programs. Final report. Colorado River Recovery Implementation Program Project No. 22D.

Bliesner, R. E., E. De La Hoz, P. B. Holden, and V. L. Lamarra. 2008. Geomorphology, hydrology, and habitat studies. Annual Report. San Juan River Basin Recovery Implementation Program, USFWS, Albuquerque, NM. 110 pp.

Bliesner, R. E., E. De La Hoz, P. B. Holden, and V. L. Lamarra. 2009. Geomorphology, hydrology, and habitat studies. Annual Report. San Juan River Basin Recovery Implementation Program, USFWS, Albuquerque, NM. 63 pp.

Box, G. E. P. 1954. Some theorems on quadratic forms applied in the study of analysis of variance problems. *Annals of Statistics* 25:290-302.

Bozek, M. A., L. J. Paulson, and G. R. Wilde. 1990. Effects of ambient Lake Mohave temperatures on development, oxygen consumption, and hatching success of the razorback sucker. *Environmental Biology of Fishes* 27:255-263.

Brandenburg, W. H. and K. B. Gido. 1999. Predation by nonnative fish on native fishes in the San Juan River, New Mexico and Utah. *The Southwestern Naturalist* 44: 392-394

Brandenburg, W. H. and M. A. Farrington. 2010. Colorado pikeminnow and razorback sucker larval fish survey in the San Juan River during 2009. Annual Report. San Juan River Basin Recovery Implementation Program, USFWS, Albuquerque, NM. 61 pp.

Clarkson, R. W. and M. R. Childs. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. *Copeia* 2000:402-412.

Douglas, M. E. and P. C. Marsh. 1998. Population and survival estimates of *Catostomus latipinnis* in Northern Grand Canyon, with distribution and abundance of hybrids with *Xyrauchen texanus*. *Copeia* 1998:915-925.

Hamman, R. L. 1981. Spawning and culture of Colorado squawfish in raceways. *Progressive Fish Culturist* 43:173-177.

Hamman, R. L. 1986. Induced spawning of hatchery-reared Colorado squawfish. *Progressive Fish Culturist* 48:72-74.

Harvey, B. C. 1991. Interaction of abiotic and biotic factors influences larval fish survival in an Oklahoma stream. *Canadian Journal of Fisheries and Aquatic Science* 48:1476-1480.

Haynes, C. M., T. A. Lytle, E. J. Wick, and R. T. Muth. 1984. Larval Colorado squawfish (*Ptychocheilus lucius*) in the Upper Colorado River Basin, Colorado. *The Southwestern Naturalist* 29:21-33.

Holden, P. B. and E. J. Wick. 1982. Life history and prospects for recovery of Colorado squawfish. *In*: W. H. Miller, H. M. Tyus, and C. A. Carlson, (eds.) Fishes of the upper Colorado River system: Present and future, Bethesda, MD: Western Division, American Fisheries Society. 98-108 pp.

Houde, E. D. 1987. Fish early life dynamics and recruitment variability. *American Fisheries Society Symposium Series* 2:17-29.

Jennings, M. J. and D. P. Philipp. 1994. Biotic and abiotic factors affecting survival of early life history intervals of a stream-dwelling sunfish. *Environmental Biology of Fishes* 39:153-159.

Johnson, J. E. and R. T. Hines. 1999. Effect of suspended sediment on vulnerability of young razorback sucker to predation. *Transaction of the American Fisheries Society* 128: 648-655.

Jordan, D. S. 1891. Reports of explorations in Colorado and Utah during the summer of 1889, with an account of the fish found in each of the river basins examined. Bulletin of the U.S. Fish Commission 89:1-40.

Kaeding, L. R. and Osmundson, D. B. 1988. Interaction of slow growth and increased early-life mortality: an hypothesis on the decline of Colorado pikeminnow in the upstream regions of its historic range. *Environmental Biology of Fishes* 22:287-298.

Lashmett, K. 1993. Young-of-the-year fish survey of the lower San Juan River 1993. Unpublished report San Juan River Basin Recovery Implementation Program. Bureau of Reclamation, Durango, CO. 82 pp.

Miller, T. J., L. B. Crowder, J. A. Rice, and E. A. Marschall. 1988. Larval size and recruitment mechanisms in fishes: towards a conceptual framework. *Canadian Journal of Fisheries Aquatic Science* 45:1657-1670.

Minckley, W. L., and J. E. Deacon. 1968. Southwestern fishes and the enigma of “endangered species”. *Science* 159:1424-1433.

Minckley, W. L. 1973. Fishes of Arizona. Phoenix: Arizona Game and Fish Department.

Moore, D. S. 1995. The basic practice of statistics. NY: Freeman and Co.

Moyle, P. B. 2002. Inland fishes of California. Berkeley: University of California Press.

Muth, R. T. and J. C. Schmulbach. 1984. Downstream transport of fish larvae in a shallow prairie river. *Transactions of the American Fisheries Society* 113:224-230.

Muth, R. T., G. B. Haines, S. M. Meismer, E. J. Wick, T. E. Chart, D. E. Snyder, and J. M. Bundy. 1998. Reproduction and early life history of razorback sucker in the Green River, Utah and Colorado, 1992 - 1996. Final Report of Colorado State University Larval Fish Laboratory to Upper Colorado River Endangered Fish Recovery Program, Denver, CO.

Nelson, J. S., E. J. Crossman, H. Espinosa-Perez, L. T. Findley, C. R. Gilbert, R. N. Lea, and J. D. Williams. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. American Fisheries Society special publication 29, Bethesda, MD.

Nesler, T. P., R. T. Muth, and A. F. Wasowicz. 1988. Evidence for baseline flow spikes as spawning cues for Colorado squawfish in the Yampa River, Colorado. *American Fisheries Society Symposium* 5:68-79.

Osmundson, D. B., R. J. Ryel, V. L. Lamarra and J. Pitlick. 2002. Flow sediment- biota relations: implications for river regulation effects on native fish abundance. *Ecological Applications* 12:1719-1739

Pavlov, D. S. 1994. The downstream migration of young fishes in rivers: mechanisms and distribution. *Folia Zoologica* 43:193-208.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestagaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1998. The natural flow regime: A paradigm for river conservation and restoration. *Bioscience* 47:769-784.

Propst, D. L., A. H. Kingsbury, and R. D. Larson. 2003. Small Bodied Fishes Monitoring, San Juan River, 1998-2002. San Juan River Basin Recovery Implementation Program, USFWS, Albuquerque, NM. 58 pp.

San Juan River Basin Recovery Implementation Program. 2011. Long-range plan. San Juan River Basin Recovery Implementation Program, USFWS, Albuquerque, New Mexico.

Snyder, D. E. 1981. Contributions to a guide to the cypriniform fish larvae of the Upper Colorado River system in Colorado. U.S. Bureau of Land Management, Biological Sciences Series 3, Denver, CO. 81 pp.

Snyder, D. E. and R. T. Muth. 2004. Catostomid fish larvae and early juveniles of the upper Colorado River Basin- morphological descriptions, comparisons, and computer-interactive key. *Colorado Division of Wildlife Technical Publication* No. 42.

Tyus, H. M. 1990. Potamodromy and reproduction of Colorado squawfish in the Green River basin, Colorado and Utah. *Transactions of the American Fisheries Society* 119:1035-1047.

Tyus, H. M. 1991. Ecology and management of Colorado squawfish. *In*: W. L. Minckley and J. E. Deacon, (eds.) Battle Against Extinction: Native Fish Management in the American Southwest, University of Arizona Press, Tucson, AZ. 379-402 pp.

Tyus, H. M. and C. A. Karp. 1990. Spawning and movements of razorback sucker, *Xyrauchen texanus*, in the Green River Basin of Colorado and Utah. *The Southwestern Naturalist* 35:427-433.

VTN Consolidated, Inc., and Museum of Northern Arizona. 1978. Fish, wildlife, and habitat assessment; San Juan River, New Mexico and Utah. Gallup-Navajo Indian water supply project. VTN Consolidated, Inc., Irvine, CA. 241 pp.

Appendix A

Figure A-1 Example of field data recorded at each sampling locality.

Field No.: MAF12-064
*PERI site

Date: 15May2012 / Acc. No.: 2012-IV:16

State/Country: NM/USA Locality: San Juan River @ RM 128.6

County: San Juan Drainage: San Juan Quad.: Sallies Spring

Coordinate System: UTM Datum: NAD27 Zone: 12S

Start: E/W: 683762 N/S: 4088260 Stop: E/W: N/S:

Shore Description: Sand, silt Air Temp.: 35 °C

Water Description: Pool

Substrate: Sand, silt Water Depth: .01-.30 m

Aquatic Vegetation / Cover: None /

Water Temp.: 18 °C Velocity (est.): 0-0.2 m/s Width (est.): 4 m Secchi Depth: 6 cm

D.O.: 7.04 mg/l Conductivity (µS): C 412 / Sc 477 Salinity: .23 ppt pH: 7.96

Method of Capture: Larval Seine /

Hauls: 4 Area: 17.3 m² Shocking Sec.: Volts: Amps:

Collectors: JLHester, BLChristman

Time: (start) 14:44 h (stop) 15:05 h Notes taken by: JLHester

Orig. Preservative: 95% EtOH Photographs: 1717

Released fishes: Yes No (list separately): Ptyluc (IL 55, 8L 43) Larval fishes Yes No

Hauls - 4.3, 5.4, 2.6, 5.0M

This site produced many larval fish. We collected alot of larvae here, possibly the most of any one site on this trip. We also had our most productive single haul at this site of the trip. This pool had many places with low velocity habitat. It's gotten progressively windier throughout the day + it has been consistently downstream.

Table A-1. Locality and description of monitoring sites designated for habitat persistence.

River Mile	Reach	Easting	Northing	Locality description
124.8	4	678281	4091267	lateral wash river left
119.5	4	675632	4096476	lateral wash river left
118.5	4	674456	4097745	lateral wash river left
116.9	4	673442	4100108	lateral wash Cowboy Wash
104.4	3	663008	4115111	lateral wash river left
96.4	3	654559	4123661	lateral wash Allen Canyon
92.2	3	648003	4125824	lateral wash Montezuma Creek
84.1	3	635458	4127339	lateral wash Recapture Creek
57.9	2	603144	4115670	lateral wash Lime Creek
52.4	2	601301	4111310	lateral wash Gypsum Creek
17.7	2	575497	4130142	lateral canyon Slickhorn Canyon
16.4	1	573427	4130259	lateral canyon river right
10.0	1	563449	4126456	lateral canyon Buckhorn Canyon
8.1	1	561124	4128666	lateral canyon Steer Gulch
3.3	1	553978	4127054	lateral wash river right

Table A-2. Summary of age-0 fishes collected in the San Juan River during the 2012 larval fish survey. Effort =8269.8m^2.

SPECIES	RESIDENCE STATUS[1]	TOTAL NUMBER OF SPECIMENS	PERCENT OF TOTAL	CPUE[2]	FREQUENCY OF OCCURRENCE[3]	% FREQUENCY OF OCCURRENCE[3]
CARPS AND MINNOWS						
red shiner	I	6,732	24.1	80.7	84	28.4
common carp	I	53	0.2	0.6	4	1.4
roundtail chub	N	2	*	*	1	0.3
fathead minnow	I	1,416	5.1	17.0	66	22.3
Colorado pikeminnow	N	-	-	-	-	-
speckled dace	N	2,043	7.3	24.5	140	47.3
SUCKERS						
flannelmouth sucker	N	7,162	25.7	85.9	167	56.4
bluehead sucker	N	7,944	28.5	95.3	134	45.3
razorback sucker	N	1,778	6.4	21.3	51	17.2
razorback X flannelmouth sucker	N	-	-	-	-	-
BULLHEAD CATFISHES						
black bullhead	I	65	0.2	0.8	21	7.1
yellow bullhead	I	2	*	*	2	0.7
channel catfish	I	282	1.0	3.4	52	17.6
TROUT						
kokanee salmon	I	-	-	-	-	-
KILLIFISHES						
plains killifish	I	23	0.1	0.3	9	3.0
LIVEBEARERS						
western mosquitofish	I	377	1.4	4.5	52	17.6
SUNFISHES						
green sunfish	I	-	-	-	-	-
bluegill	I	-	-	-	-	-
largemouth bass	I	9	*	0.1	7	2.4
TOTAL		27,888		334.4		

[1] N = native; I = introduced
[2] CPUE = catch per unit effort; value based on catch per 100 m^2 (surface area) sampled
[3] Frequency and % frequency of occurrence are based on *n* = 296 samples.
* Value is less than 0.05%

Table A-3. Summary of age-1+ fishes collected in the San Juan River during the 2012 larval fish survey. Effort =8,269.8 m^2

SPECIES	RESIDENCE STATUS[1]	TOTAL NUMBER OF SPECIMENS	PERCENT OF TOTAL	CPUE[2]	FREQUENCY OF OCCURRENCE[3]	% FREQUENCY OF OCCURRENCE[3]
CARPS AND MINNOWS						
red shiner	I	1,091	73.2	13.1	99	33.2
common carp	I	-	-	-	-	-
roundtail chub	N	-	-	-	-	-
fathead minnow	I	34	2.3	0.4	15	5.0
Colorado pikeminnow	N	114	7.6	1.4	29	9.7
speckled dace	N	56	3.8	0.7	26	8.7
SUCKERS						
flannelmouth sucker	N	21	1.4	0.3	15	5.0
bluehead sucker	N	-	-	-	-	-
razorback sucker	N	-	-	-	-	-
bluehead X flannelmouth sucker	N	-	-	-	-	-
BULLHEAD CATFISHES						
black bullhead	I	14	0.9	0.2	3	1.0
yellow bullhead	I	-	-	-	-	-
channel catfish	I	1	0.1	*	1	0.3
TROUT						
kokanee salmon	I	-	-	-	-	-
KILLIFISHES						
plains killifish	I	1	0.1	*	1	0.3
LIVEBEARERS						
western mosquitofish	I	160	10.7	1.9	38	12.8
SUNFISHES						
green sunfish	I	4	0.3	*	2	0.7
bluegill	I	-	-	-	-	-
largemouth bass	I	-	-	-	-	-
-						
TOTAL		1,496		17.9		

[1] N = native; I = introduced
[2] CPUE = catch per unit effort; value based on catch per 100 m^2 (surface area) sampled
[3] Frequency and % frequency of occurrence are based on n = 296 samples.
* Value is less than 0.05%

Table A-4. Summary of the age-0 razorback sucker collected in the San Juan River during the May larval fish survey.

Field Number	Number of Specimens	Total Length	Larval Stage	Date Collected	River Mile	Sampling Method
MAF12-052	1	10.7	mesolarvae	14-May-12	143.9	larval fish seine
MAF12-054	5	10.6 -11.3	proto - mesolarvae	14-May-12	142.4	larval fish seine
MAF12-056	8	10.2 -13.0	proto - mesolarvae	15-May-12	138.8	larval fish seine
MAF12-058	3	10.4 -11.0	proto - mesolarvae	15-May-12	136.3	larval fish seine
MAF12-059	1	11.6	mesolarva	15-May-12	134.5	larval fish seine
MAF12-065	1	11.3	mesolarva	15-May-12	127.2	larval fish seine
MAF12-066	37	11.0 -14.9	mesolarvae	15-May-12	124.8	larval fish seine
MAF12-069	2	11.2, 12.8	mesolarvae	16-May-12	118.9	larval fish seine
MAF12-071	1	10.8	mesolarva	16-May-12	116.9	larval fish seine
MAF12-075	140	10.1 -17.3	proto - mesolarvae	16-May-12	107.6	larval fish seine
MAF12-076	1	17.0	mesolarva	16-May-12	105.0	larval fish seine
MAF12-079	13	9.2 -14.0	mesolarvae	16-May-12	100.5	larval fish seine
MAF12-080	8	10.5 -17.5	mesolarvae	17-May-12	99.0	larval fish seine
MAF12-082	8	10.5 -12.3	proto - mesolarvae	17-May-12	94.0	larval fish seine
MAF12-083	2	11.9, 13.0	mesolarvae	17-May-12	92.7	larval fish seine
MAF12-086	10	9.5 -15.6	proto - mesolarvae	17-May-12	86.8	larval fish seine
MAF12-088	3	10.7 -12.3	mesolarvae	17-May-12	83.7	larval fish seine
MAF12-089	7	9.7 -11.5	mesolarvae	17-May-12	81.8	larval fish seine
WHB12-061	76	9.9 -12.6	proto - mesolarvae	14-May-12	75.4	larval fish seine
WHB12-062	2	11.8, 12.5	mesolarvae	14-May-12	71.2	larval fish seine
WHB12-063	46	11.6 -19.8	meso - metalarvae	14-May-12	69.9	larval fish seine
WHB12-064	5	10..1 -13.5	mesolarvae	15-May-12	68.4	larval fish seine
WHB12-067	17	13.8 -15.8	mesolarvae	15-May-12	62.2	larval fish seine
WHB12-068	3	10.6 -13.7	mesolarvae	15-May-12	61.2	larval fish seine
WHB12-070	435	8.6 -21.2	proto - mesolarvae	15-May-12	57.9	larval fish seine
WHB12-070B	244	9.5 -20.7	meso - metalarvae	15-May-12	57.9	larval fish seine
WHB12-071	7	10.7 - 12.4	mesolarvae	15-May-12	52.9	larval fish seine
WHB12-074	2	10.5, 11.0	mesolarvae	15-May-12	43.8	larval fish seine
WHB12-076	11	10.5 -13.5	mesolarvae	16-May-12	38.8	larval fish seine
WHB12-077	17	10.3 -12.9	mesolarvae	16-May-12	33.7	larval fish seine
WHB12-079	3	10.4 -12.4	mesolarvae	16-May-12	26.4	larval fish seine
WHB12-082	3	10.5 -11.5	mesolarvae	16-May-12	24.5	larval fish seine
WHB12-084	7	13.7 -21.0	meso - metalarvae	17-May-12	17.7	larval fish seine
WHB12-087	8	10.5 -12.5	mesolarvae	17-May-12	16.4	larval fish seine
WHB12-089	3	10.1 -11.5	mesolarvae	17-May-12	11.0	larval fish seine
WHB12-090	128	9.9 -16.3	proto - mesolarvae	17-May-12	10.0	larval fish seine
WHB12-092	468	10.0 -30.0	meso - juvenile	17-May-12	8.1	larval fish seine
Total	**1,736**					

Table A-5. Summary of the age-0 razorback sucker collected in the San Juan River during the June larval fish survey.

Field Number	Number of Specimens	Total Length	Larval Stage	Date Collected	River Mile	Sampling Method
MAF12-096	1	14.3	mesolarva	11-June-12	136.4	larval fish seine
MAF12-096	1	16.8	mesolarva	12-June-12	131.0	larval fish seine
MAF12-101	1	11.3	mesolarva	12-June-12	128.1	larval fish seine
MAF12-104	1	28.3	juvenile	12-June-12	122.2	larval fish seine
WHB12-113	1	12.7	mesolarva	11-June-12	69.8	larval fish seine
WHB12-115	1	13.2	mesolarva	11-June-12	67.7	larval fish seine
WHB12-116	2	18.1, 20.4	mesolarvae	12-June-12	66.2	larval fish seine
WHB12-118	1	20.5	metalarva	12-June-12	61.0	larval fish seine
WHB12-119	1	28.1	metalarva	12-June-12	58.9	larval fish seine
WHB12-120	22	14.3 -25.4	meso - juvenile	12-June-12	57.9	larval fish seine
WHB12-123	5	10.0 -31.8	meso - juvenile	12-June-12	49.0	larval fish seine
WHB12-130	1	15.5	mesolarva	13-June-12	29.5	larval fish seine
WHB12-134	3	17.2 -26.5	meso - juvenile	13-June-12	22.9	larval fish seine
WHB12-146	1	29.6	juvenile	14-June-12	3.4	larval fish seine
Total	**42**					
2012 Total	**1,778**					

Year	2011	2011	2011	2011	2011
Month/Discharge	April (564 cfs)	May (1,174 cfs)	June (8,080 cfs)	July (1,190 cfs)	August (545 cfs)
Rivermile					
124.8	Site Dry	Site Dry	Backwater	Backwater	Site Dry
119.5	Site Dry	Backwater	Backwater	Site Dry	Site Dry
118.5	Site Dry	Backwater	Backwater	Site Dry	Site Dry
116.9	Isolated pool	Backwater	Backwater	Backwater	Site Dry
104.4	Site Dry	Backwater	Backwater	Backwater	Site Dry
96.4	Site Dry	Backwater	Backwater	Backwater	Site Dry
92.2	Site Dry	Backwater	Backwater	Backwater	Site Dry
84.1	Backwater	Backwater	Backwater	Backwater	Site Dry
57.9	Isolated pool	Backwater	Backwater	Backwater	Site Dry
52.4	Isolated pool	Isolated pool	Backwater	Backwater	Site Dry
17.7	Site Dry	Backwater	Backwater	Isolated pool	Site Dry
16.4	Site Dry	Backwater	Backwater	Site Dry	Site Dry
10.	Site Dry	Backwater	Backwater	Backwater	Site Dry
8.1	Site Dry	Backwater	Backwater	Isolated pool	Site Dry
3.3	Site Dry	Backwater	Backwater	Site Dry	Site Dry
Year	2012	2012	2012	2012	2012
Month/Discharge	April (994 cfs)	May (1,117 cfs)	June (725 cfs)	July (978 cfs)	August (559 cfs)
Rivermile					
124.8	Isolated pool	Backwater	Site Dry	Backwater	Site Dry
119.5	Isolated pool	Site Dry	Site Dry	Site Dry	Site Dry
118.5	Site Dry	Backwater	Backwater	Site Dry	No Data
116.9	Backwater	Backwater	Isolated pool	Site Dry	Backwater
104.4	Site Dry	Isolated pool	Site Dry	Site Dry	Site Dry
96.4	Site Dry	Site Dry	Site Dry	Site Dry	Site Dry
92.2	Site Dry	Isolated pool	Site Dry	Site Dry	Site Dry
84.1	Site Dry	Site Dry	Site Dry	Backwater	Site Dry
57.9	Isolated pool	Isolated pool	Isolated pool	Site Dry	Site Dry
52.4	Isolated pool	Isolated pool	Site Dry	Site Dry	Backwater
17.7	Isolated pool	Isolated pool	Isolated pool	Backwater	Site Dry
16.4	Isolated pool	Isolated pool	Site Dry	Site Dry	Site Dry
10.	Isolated pool	Isolated pool	Site Dry	Isolated pool	Site Dry
8.1	Isolated pool	Isolated pool	Site Dry	Isolated pool	Site Dry
3.3	Isolated pool	Isolated pool	Site Dry	Site Dry	Site Dry

Table A-6. Habitat type of each monitoring site during 2011 and 2012. Discharge data taken from USGS gage #09379500 (Mexican Hat, UT); values are means for the week the site was sampled.